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ABSORPTION AS APPLIED TO RECOVERY OF GASOLINE LEFT IN RESIDUAL GAS FROM COMPRESSION PLANTS

BY

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ABSORPTION AS APPLIED TO RECOVERY OF GASOLINE LEFT IN RESIDUAL GAS FROM COMPRESSION PLANTS.

By W. P. Dykema and Roy O. Neal.

INTRODUCTION.

Petroleum investigations having to do with gasoline are being conducted by the Bureau of Mines in order to bring about more efficient methods of production, transportation, refining, and marketing in the United States. The war has impressed the Nation with the importance and value of gasoline as a source of power. With the ever-increasing number of gasoline-driven engines in use, especially in motor vehicles and tractors, the consumption of gasoline must be larger, and hence it is imperative that all waste of gasoline in petroleum or natural gas be reduced to the minimum.

Supplementary to the researches described in Bulletin 151, "Recovery of Gasoline from Natural Gas by Compression and Refrigeration," and Bulletin 176, "Recent Developments in the Absorption Process for Recovering Gasoline from Natural Gas," the bureau investigated the possibilities of increasing the saving of gasoline at compression plants by installing small auxiliary absorption units for treating the residual gases.

The Bartlesville experiment station of the bureau, being situated in an area that produces more gasoline from natural gas than any other in this country, was selected as the logical place for beginning this investigation. The Oklahoma Corporation Commission has listed in its files more than 230 active gasoline plants; 90 per cent of these use the compression method, which, as this study proves, is not altogether satisfactory as regards efficient recovery.

SCOPE OF REPORT.

This paper deals with the recovery of gasoline by means of the absorption process[a] from the residual gas of plants where motor

[a] Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods, Bull. 120, Bureau of Mines, 1917, 71 pp.; Dykema, W. P., Recent developments in the absorption process for recovering gasoline from natural gas, Bull. 176, Bureau of Mines, 1919, 90 pp.

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fuel is obtained from natural gas by mechanical compression and cooling. In the absorption process the gasoline present in the natural gas is absorbed by oil and subsequently separated from the oil by distillation, or is absorbed in naphtha and marketed without any further treatment.

ACKNOWLEDGMENTS.

The writers recognize the valuable suggestions and the hearty cooperation rendered by many of the plant operators and thank particularly Messrs. O. J. Berend, W. H. McCrum, R. M. Young, B. Parks, F. V. Faulkner, Philip Jones, W. E. Burke, F. E. Richardson, J. J. Allison, W. R. McGinnis, P. R. Chamberlain, Frank Phillips, W. H. Bowen, W. M. Welch, and Neal Muir for the courtesy of permitting the bureau's representatives to use their plants for tests and experiments.

The writers wish also to express their appreciation for the numerous suggestions made by Messrs. J. D. Creveling, Carl Holt, Thomas R. Weymouth, and P. M. Biddison, who have for years devoted their time and energy to absorption process and gas problems.

J. O. Lewis, the present chief of the petroleum division of the Bureau of Mines, has been in close touch with the field work and has shown untiring interest in the investigation. W. G. Hiatt, E. W. Dean, and J. G. Shumate, all members of the bureau's staff, rendered valuable and efficient cooperation.

OBJECTIONS TO INSTALLING ABSORPTION PROCESS AT COMPRESSION PLANTS.

Through the efforts of engineers applying absorption practice and principles in the treatment of the rich (casing-head) gases being treated almost entirely by compression, the absorption method has been proved to be more efficient than compression and to be applicable either to the rich gas (3 to 6 gallons per 1,000 cubic feet) or to the residual gases from compression plants. Some of the most efficient gasoline plants in the Mid-Continent field use the absorption process. The engineers in charge deserve much credit, as plant owners were skeptical of the success of absorption in replacing compression. Similarly the prejudice of operators has to be overcome in installing absorption towers to treat the residual gas from compression plants. The chief objections advanced against equipping a plant with an auxiliary absorption unit for treating the waste gas are that the gasoline recovered is too "wild" to hold, and that in most instances the quantity so obtained would be too small to make such an auxiliary unit profitable.

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COST OF ABSORPTION.

As a concrete example of cost and gain, let it be assumed that from the residual gas of a compression plant 0.40 gallon of gasoline can be recovered per 1,000 cubic feet of residual gas, the daily capacity being 500,000 cubic feet of this gas and the working pressure 200 pounds.

If the absorption medium used were naphtha, the only extra construction required would be one absorption tower and auxiliaries such as pumps, etc., with no additional labor cost for operation. This installation can be made at a small (500,000 cubic feet) plant at a cost of less than $1,000. With absorption gasoline at 22 cents per gallon, the gross income in such an installation would be $1,320 per month, excluding from consideration the increase in volume and gravity of the naphtha through some of the higher gases being permanently held in solution.

Under the same assumption of gas to be treated, the first cost of a plant using "mineral seal oil" as the absorbent, with subsequent distillation to separate the gasoline, should not exceed $6,000. The operating costs chargeable to the absorption process would be represented by the wages of one extra man on each tour, plus upkeep costs.

QUALITY OF PRODUCT OBTAINED.

An erroneous impression is current among compression-plant operators to the effect that only the very lightest of the condensible vapors are retained in the treated gas being discharged from the plant.

On the assumption that a compression plant in the Mid-Continent field is working at a pressure of 214 pounds per square inch, the treated gas, if cooled to 90° F. before discharge, will theoretically contain 0.5 gallon of hexane (gravity 78.9° B.) per 1,000 cubic feet, and if cooled to 70° F. will contain 0.39 gallon per 1,000 cubic feet, as shown by the curve in figure 1. In other words, by compression and cooling it is theoretically impossible to reduce the content of hexane below 0.5 gallon per 1,000 cubic feet at 214 pounds and 90° F., or below 0.39 gallon at 214 pounds and 70° F. At 90° F. and a pressure of 214 pounds the residual gas would also contain 0.17 gallon of heptane (gravity 70.9° B.), and at 70° F., 0.11 gallon of heptane per 1,000 cubic feet, and correspondingly smaller quantities of the heavier members of the hydrocarbon series.

These data show that regardless of what the working pressure or temperature may be in the compression system, the treated gas will contain some low-gravity hydrocarbons. Evidently operators are laboring under a false apprehension when they say that the gasoline

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in the residual gas is so wild that even if recovery were possible the gasoline would rapidly weather away.

THE EFFICIENCY OF THE COMPRESSION SYSTEM.

In the operation of compression plants, which are described in Bulletins 88 and 151, three prime factors control the efficiency of recovery—namely, the working pressure, the temperature to which the compressed gas is cooled, and dilution of the gas with air, carbon dioxide, or "dry" gas.

PRESSURES.

Plant operators have been repeatedly urged to make a series of experimental runs to determine the most suitable working pressure for the particular gas being treated. The criterion as to the pressure used at new plants is that used by other plants in the same field or in some other field with which the operators may be familiar. As a

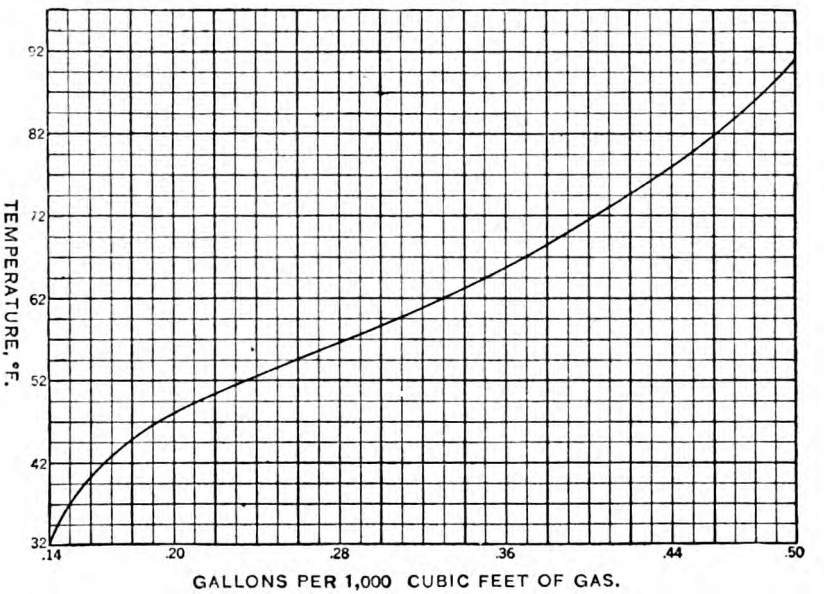

FIGURE 1.—Curve showing the theoretical amount of hexane left in the residual gas from compression plants at different working temperatures. Based on the assumption that gas is treated at a pressure of 214 pounds per square inch.

field gets older and the vacuums are increased the gasoline content of the gas increases, consequently, lower pressures can be used and still produce the maximum quantity of salable product. This feature must be considered if plants are to be operated efficiently.

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TEMPERATURES.

In the compression system, temperature conditions are just as important as pressure conditions, because these two factors are interchangeable. A mistake made by many operators is using too much water and flooding the coils. When an excess of water is used, the greatest cooling factor, evaporation, is not effective in lowering the water temperature and the heat is transferred to the water, as in a submerged coil or in an oil heat-exchanger. Coils should have only a thin film of water covering them in order to get the maximum cooling effect from radiation and evaporation. One pound of water, on warming from 79° F. to 80° F., will absorb 1 B. t. u., provided there is no evaporation, whereas a pound of water permitted to evaporate will absorb 992 B. t. u. From this it is evident that too much water is more detrimental than too small a quantity. Submerged coils are not recommended in the recovery of casing-head gasoline, for the reason that evaporation is at a minimum in such cooling systems. With aerial coils it is possible at times to obtain temperatures as low as 65° F. on a warm summer day, the reduction in temperature depending on the relative humidity of the air, whereas with submerged coils the lowest temperatures that could be expected would be the original temperatures of the incoming water.

A large number of the compression plants visited have kept absolutely no record of temperatures; in fact, at some plants the only thermometer on hand was that on the stem of the hydrometer. Thermometer wells should be placed in the gas stream at convenient points ahead of and after each step in the process, whether compressing, cooling, or expanding.

DILUTION OF GAS.

At a majority of the plants in the Mid-Continent field practically no attention is paid to the dilution of the casing-head gas with dry gas and more especially with air. The gas is contaminated with air through leaks in the vacuum lines, defective casing heads, improperly packed stuffing boxes, and leaky stopcocks; also, in some instances by perforated casing at or near the surface of the ground. One can readily ascertain the air content by means of a small portable gas-analysis apparatus, which is on the market. However, because chemicals and some glass bulbs are employed in this apparatus, most of the operators neglect it, thinking that none but a skilled chemist could use it.

One gasoline company operating in the Glenn pool has a small force of men who are engaged continually in taking gas samples from various lines, analyzing them for air content, following up the lines showing high percentages, and, if possible, determining the

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source of the incoming air and making the necessary corrections. The result is that the plant is now treating between two-thirds and one-half as much air as formerly, thus reducing the air content to 19 per cent.

Dry gas is just as detrimental as air as a diluent of natural gas to be treated. In one instance that came to the writers' attention natural gas containing 1 gallon of gasoline per 1,000 cubic feet was being drawn into the same line as gas having a gasoline content of 7 gallons per 1,000 cubic feet. On discarding the entire supply of the 1-gallon gas, the production was increased, lower pressures employed, and the quality of the product materially improved. Some plants have two sets of coils and compressors where two gases of decidedly different richness are treated, and if the gas supplies will warrant it, this is excellent practice. Determination of the specific gravity (air-free basis) of a gas will usually indicate the quality, and the result, in all cases, should be confirmed by a compression or absorption test before plant construction is considered.

LIMITATIONS OF COMPRESSION PROCESS.

It is impossible to recover all of the gasoline in casing-head gas by means of compression unless excessive pressures or extremely low pressures are maintained. Even with rich gas the efficiency of recovery necessarily decreases as the gas gets leaner and the resulting partial pressures of the condensible vapors increase. It has been stated[a] that the compression system will remove all of the gasoline from wet casing-head gas, certainly from gases containing 2 gallons or more per 1,000 cubic feet. The writers have tested the residual gas from compression plants operating at 72° F. (temperature of gas in accumulators) on 10-gallon gas and have found the plants losing as much as 340 gallons per 1,000,000 cubic feet, which could undoubtedly be recovered at a profit by absorption. Compression alone should never be used in treating gas containing less than 1.00 gallon per 1,000 cubic feet, and has failed to give satisfactory yields in some instances on gas carrying as much as 1 gallon of condensible gasoline.

PARTIAL VAPOR PRESSURES.

The underlying principles governing all processes used for recovering gasoline from natural gas involve the partial vapor pressures of the gasoline hydrocarbons, and in order to have a clear understanding of the various processes a knowledge of the theory of partial pressures and its application is necessary.

[a] Burrell, G. A., Gasoline plants and their operation: Oil and Gas Jour., vol. 17, Feb. 7, 1919, p. 54.

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All gases will diffuse into one another, and in a confined mixture the process of diffusion goes on until each gas is uniformly distributed throughout the entire space. If the pressure of each gas could be measured separately, it would be found that diffusion continues until the pressure of any given gas is the same in all parts of the space; also it would be found that the pressure exerted by each gas is the same as that which the given mass of the gas would have exerted if it alone were occupying the entire space. This pressure is called its partial vapor pressure. The total pressure of a gaseous mixture is the sum of all the partial pressures of its component gases. The volume of each gas is the total volume of the space occupied by the entire gaseous mixture. The law which describes these phenomena is known as Dalton's law of partial pressures, and is stated by one authority[a] as follows:

"Each gas in a gaseous mixture fills the entire space occupied by the gaseous mixture, and the total pressure of the mixture is the same as the sum of the partial pressures of the component gases."

Let the total volume be represented by V, the volume of the separate gases by V_a, V_b, V_c, the total pressure by P, and the partial pressures by P_a, P_b, and P_c. Then—

$$V_a = V_b = V_c = V$$
$$P_a + P_b + P_c = P$$

TABLE 1.—*Vapor pressures and corresponding temperatures at which certain hydrocarbons will condense.*[a]

Temperature (° F.).	Vapor pressure (pounds per square inch).				
	Propane (C_3H_8).	Butane (C_4H_{10}).	Pentane (C_5H_{12}).	Hexane (C_6H_{14}).	Heptane (C_7H_{16}).
32	72.5	15.9	3.5	0.9	0.2
40	84.6	19.9	4.4	1.0	.3
50	100.7	24.1	5.4	1.4	.4
60	115.4	30.0	6.8	2.0	.5
70	130.1	36.7	8.2	2.5	.7
80	147.2	44.1	9.9	2.9	.9
90	165.0	53.2	11.9	3.2	1.1

[a] Diserns, P., Recovery of gasoline from casing-head and natural gas: Jour. Engineers' Club of St. Louis, Jan.–Feb., 1918.

For example, assume that a natural gas contains 1.5 per cent by volume of hexane (which is approximately 0.5 gallon per 1,000 cubic feet) at 80° F. The vapor pressure of hexane at 80° F. is 2.9 pounds per square inch, as is stated in Table 1. The pressure necessary before the hexane will start to precipitate is $(100 \div 1.5) \times 2.9$ or 193 pounds per square inch. The pressures necessary to cause the hexane to start to condense at other temperatures is shown by the curve in figure 2.

[a] Cady, H. P., Inorganic chemistry. 1912. p. 61.

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If this natural gas is contaminated with an equal volume of dry gas or air, the hexane content will be decreased to 0.75 per cent, and a pressure of 386 pounds per square inch will have to be applied before the hexane will start to condense. The same reasoning applies to pentane, heptane, and other gasoline vapors in casing-head gas, and on the partial vapor pressure of each component depends the pressure at which the compressor must be worked in order to precipitate the gasoline.

In the absorption process, partial pressures of the various recoverable constituents are equally important. Each particular hydrocarbon continues to dissolve in the absorption medium until

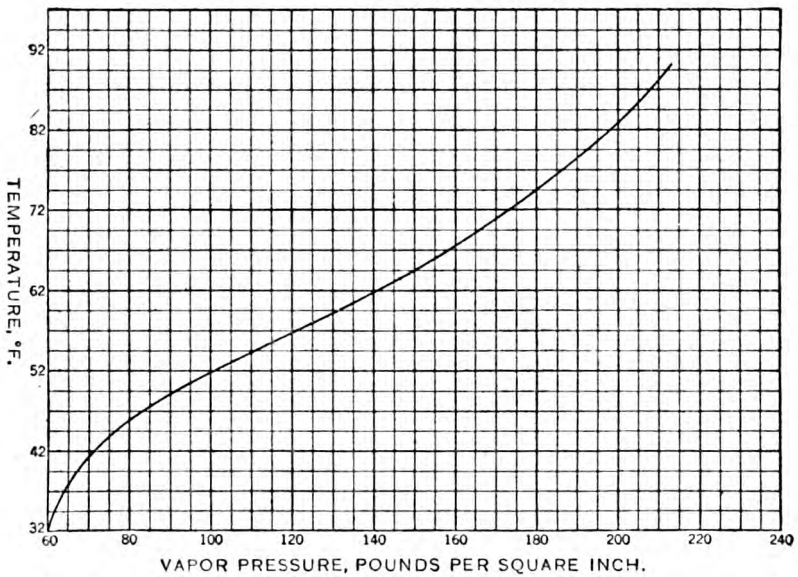

FIGURE 2.—Curve showing the partial vapor pressure of hexane at different temperatures. Assumption is made that the hexane is present in gas containing 0.5 gallon hexane per 1,000 cubic feet, and that 1 gallon of hexane occupies 30 cubic feet.

its partial vapor pressure in the gas is equal to its partial vapor pressure from the absorption menstruum. For example, hexane in a mixture of gases will dissolve in "mineral seal oil" until its partial vapor pressure from the oil is at equilibrium with its partial vapor pressure in the gas. Each individual hydrocarbon is absolutely independent of all others. Consequently, one can not say that 4 per cent or any other figure is the best saturation at which to operate an absorption plant until some experimental work has been done. The character and proportions of the different hydrocarbons present in the gas will determine what saturation is the most efficient to use. It is obvious that a gas containing, say, 0.5 per cent pentane, 0.5 per cent hexane, and 0.5 per cent heptane can be treated with less

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oil (other factors being equal) than a gas containing 1.5 per cent pentane, because the solubility of each component is independent of other gases. At an absorption plant treating "dry" natural gas from the Mid-Continent field having a gasoline content of 0.20 gallon per 1,000 cubic feet, and circulating 5 or 6 gallons of "mineral seal oil" per 1,000 feet of gas treated, at normal temperatures, the discharge gas will retain between 0.02 and 0.03 gallon of uncondensed gasoline. This represents the point of equilibrium between the partial vapor pressures of that portion of the hydrocarbons dissolved in the "mineral seal oil" and the portion in the gas.

FIELD TESTS OF PLANTS FOR LOSSES OF GASOLINE.

DATA ON COMPRESSION PLANTS.

The residual gas from compression plants situated in representative districts of the Mid-Continent field was tested by the absorption apparatus described in a subsequent part of this paper (pp. 36 to 38). The data obtained is tabulated in Table 2 following.

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TABLE 2.—*Data on compression plants in Oklahoma tested for losses of gasoline in residual gas.*

Field or district.	Plant No.	Capacity (M cubic feet).	Daily production (gallons).	Recovery (gallons per M cubic feet).	Discharge pressure (pounds per square inch).		Rated hp.	Low-pressure cooling coils.		High-pressure cooling coils.		Method of blending.	Atmospheric temperature during test (°F.).	Temperature of gas discharged from high-pressure accumulators (°F.).	Temperature of water in pit (°F.).	Gasoline content of residue (gallons per M cubic feet).
					Low stage.	High stage.		Sq. ft. / Hp.	Sq. ft. / 1000 cu. ft.	Sq. ft. / Hp.	Sq. ft. / 1000 cu. ft.					
Bartlesville field	1	500	650	1.30	20	250	160	7.05	1.13	14.0	2.26	In stock tanks	84		69	[a] 0.480
	2	1,000	6,540	6.5	42	275	450	5.0	1.2	6.8	1.5	do	86	84	77	[b] .200
	3				60	250	75	8.6		20.0		do	97		80	.808
	4	250	400	1.6	35	250	135					do	98		74	.390
	5	900	2,000	2.2	35	275	240	2.0	.34	4.2	1.1	In coils	77		71	[c] .336
	6	300	640	2.1	40	270	150	4.2	1.0	8.5	2.2	In stock tanks	67		65	.245
	7	800	1,000	1.2	40	235	550					In coils	58		72	[d] .190
Nowata district	8	300	600	2.0	45	250	180	14.6	4.4	14.6	4.4	In stock tanks	86		71	.550
	9	600	3,000	5.0		250	375	5.8	1.8	5.8	1.8	In coils	95			.280
	10	100	250	2.5	35	260	60	6.2	1.9	8.2	2.4	do	100			.687
	11	2,500	15,000	6.0	20	275	750					do	100			[e] .11
Sapulpa district	12	600	3,000	5.0	40	250	210	4.6	.8	6.8	1.2	In stock tanks	75		69	[f] .390
	13	200	430	2.2	30	275	70						75			.630
	14	800	1,800	2.2	30	275	365	2.6	.6	9.9	1.5	In coils	70		57	.30
	15	500	900	1.8	40	275	255	2.8	.72	5.6	1.4	do	75		57	.31
	16	60	150	2.5	45	300	50	4.0	1.6	4.8	2.0	Not blended	77		75	.46
	17	200	1,200	6.0	25	285	55	6.8	1.2	10.2	1.8	In stock tanks	72		63	.32
	18	300	3,000	10.0		200	80	5.0	.66	9.0	1.2	Not blended	72		72	.34
Okmulgee district	19	600	1,600	2.66	40	300	180	3.2	.67	4.0	.80	In stock tanks	75	68	61	.38
	20	200	1,700	8.5	30	180	120	3.4	1.2	4.2	1.5		91		77	.28
	21	800	2,200	2.75	35	275	340					In coils	82		78	.27
	22	150	250	1.67	35	250	100	4.4	1.9	6.8	2.2	In stock tanks	72		68	.15
	23	1,000	1,750	1.75	38	300	230	10.8	1.6	16.2	2.4	In coils	79		66	.35
	24	600	1,500	2.50	20	275	320	2.0	.5	3.1	1.0	do	86		71	.43
Cushing field	25	760	5,000	6.6	35	250	380	7.6	1.9	7.6	1.9	In stock tanks	69		65	.14
	26	900	5,000	5.5	20	225	660					do	58		54	[g] .13
	27	600	1,600	2.66			235	2.4	.47	3.0	6.0	do	68	70	71	.15

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	28	2,000	13,000	6.50	60	200	800	.....	.....	.....	.....	In coils.....	60	.....	.....	h.15
	29	3,500	22,000	6.3	45	310	1,440	4.2	1.0	8.4	2.0	Not blended....	61	63	68	.21
	30	700	2,000	2.8	35	290	330	4.2	.....	2.0	.....	.....do.....	68	67	.....	.44
Average.....	.....	.....	.....	.....	.....	.....	.....	5.3	1.26	7.9	1.7	.....	.....	.....	.....	.337

aSince this test was made three vertical towers using naphtha as the absorption medium have been erected and the content of gasoline in the residual gas reduced to 0.10 gallon per 1,000 cubic feet.
bUses a two-stage expansion engine, which cools the expanding gas to 28° F.
cResidual gas was run through a vertical tower, which reduced residual gas to 0.14 gallon per 1,000 cubic feet.
dUses submerged coils.
eUses a two-stage expansion engine where expanding gas is cooled to 25° F. below zero.
fBlends in storage tanks with gas oil of 35° B. gravity.
gResidual gas is treated by absorption plant, which decreases gasoline content to 0.028 gallon per 1,000 cubic feet.
hResidual gas is treated in absorption system, using naphtha which has been cooled by ammonia process to 35° F.

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DISCUSSION OF PLANTS AND RESULTS OBTAINED.

PLANT 1

The first plant tested, designated as No. 1, is in the Bartlesville field. The results of the investigation showed that the plant was losing 0.480 gallon per 1,000 cubic feet of gas. Efforts to increase the production by mechanical adjustments, such as changing the pressures and temperatures used and examining the raw gas for dilution with air or dry gas, were in vain. The bureau's representatives recommended the erection of absorption towers to treat the residue gas, using naphtha as the absorption agent, if possible. A preliminary test with the portable absorption apparatus, using naphtha, gave the following results:

Results of testing residual gas.

[Temperature of naphtha at beginning of test, 72° F.; at finish, 82° F.; average, 77° F. Pressure, 265 pounds per square inch. Rate of flow, 141 cubic feet per hour (test lasted 1 hour 25 minutes) or 2.35 cubic feet per minute. Volume, 200 cubic feet.]

	First compartment.	Second compartment.	Third compartment.
Charge.....c. c..	2,600	2,600	2,600
Recovered.....c. c..	3,100	2,940	2,720
Increase in volume.....per cent..	15.4	13.1	4.6
Initial boiling point.....°F...	114	119	129
Gravity.....°Be..	56.1	54.6	51.7
Vapor pressure at 100°F [a].....pounds per square inch..	3.5	2.7	2.0
Gravity, after vapor pressure had been taken.....°Be..	54.8	53.3	51.5

[a] Minimum temperature of charge was 82° F., therefore vapor pressure at 70° F. could not be determined.

The volume of naphtha was increased by 15.4 per cent. in the first compartment and the gravity raised from 51.1° to 56.1° B., whereas the vapor pressure at 100° F. was only 3.5 pounds per square inch. The distillation curves of products recovered in each compartment is given in figure 3. For convenience the curves have been drawn to coincide above 60 per cent, but, as a matter of fact, they deviate slightly from each other.

The absorption system installed at the plant referred to has three towers, each consisting of a 20-foot joint of 20-inch standard casing, connected in series. Steel shavings are used as baffling material having approximately 90 per cent voidage. Each tower was filled to a depth of about eight feet with naphtha of 50° to 52° B. gravity. The gas bubbles through the naphtha until the product in the first absorber reaches a gravity of 63° B., at which time the stock in the second and the third towers attains gravities of 58° B. and 57° B., respectively. The time required for running one charge is usually eight hours. The product from

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the three towers when mixed in the storage tank has a gravity of approximately 59° B. and a vapor pressure of about seven pounds per square inch. The extremes of quantities used and products made in the operation of these towers in the first month of operation are as follows:

	Highest run.	Lowest run.
Gas treated, M cubic feet	511	500
Blended product obtained, gallons	1,213	963
Naphtha used, gallons	791	700
Gain, gallons	422	263

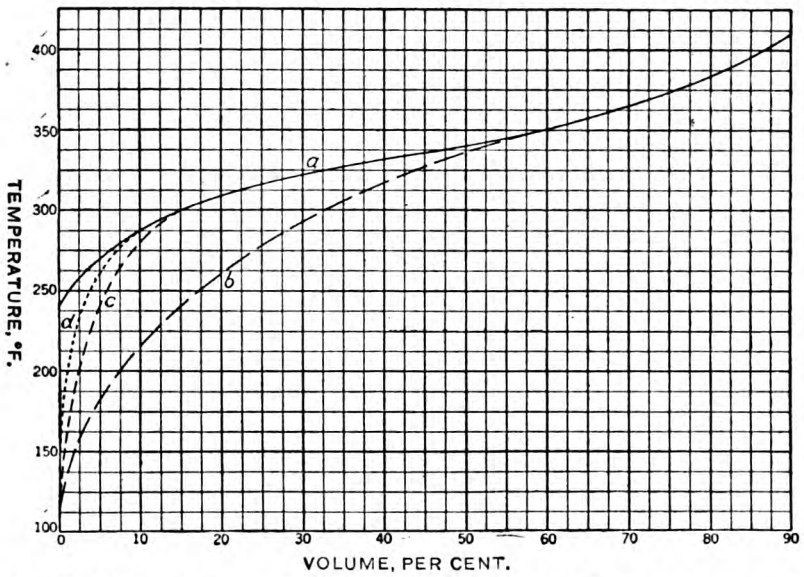

FIGURE 3.—Distillation curves for raw naphtha and products from absorbers, plant 1. *a*, Raw naphtha; *b*, first absorber; *c*, second absorber; *d*, third absorber.

Distillation curves for the naphtha charged into absorption towers and for the blend obtained on mixing the absorption products from the three towers are shown in figure 4. Results of tests to determine the weathering losses of the various products at this plant are given in Table 3. In these tests graduated cylinders of 500 c. c. capacity were filled with the samples. Temperatures during weathering varied from 51° F. to 72° F. The data recorded are significantly comparative.

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TABLE 3.—*Results of weathering tests of naphtha and blended products, plant 1.*

Time.	Naphtha. [a]		Compression blend. [b]		Absorption blend. [c]	
	Gravity.	Loss.	Gravity.	Loss.	Gravity.	Loss.
Hours.	° *B.*	*Per cent.*	° *B.*	*Per cent.*	° *B.*	*Per cent.*
0	50.8	0	63.4	0	61.5	0
2	50.8	0	63.0	1.0	61.2	1.0
4	50.7	.5	62.6	2.3	60.6	2.5
6	50.6	.7	62.4	3.2	60.4	3.5
24	50.6	1.2	60.4	8.4	58.7	8.5
48	50.5	2.0	59.4	12.0	57.8	11.8

[a] Naphtha used in making blends.
[b] Product made by blending naphtha and condensate from high-pressure and low-pressure accumulators of compression units.
[c] Stock made by absorption towers through which the residual gas passed.

The residual gas now averages 0.10 gallon of gasoline per 1,000 cubic feet of gas, whereas before the naphtha absorbers were put into operation the residual gas from the compression plant carried 0.50

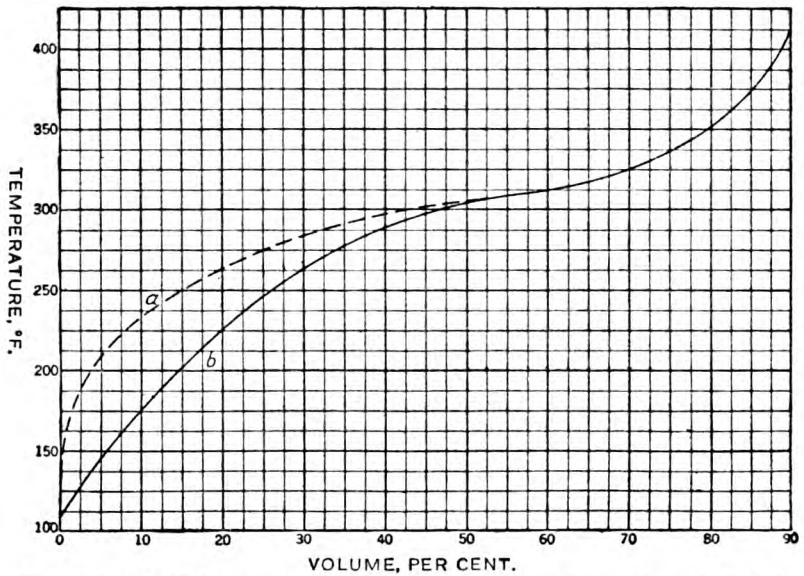

FIGURE 4.—Distillation curves for naphtha used and blended product, at plant 1. *a*. Naphtha, *b*, blended product.

gallon per 1,000 cubic feet. The pressure on the discharge of the high-stage compressor is 250 pounds per square inch, the same as before the absorption unit was installed to treat the residue gas, also the production of condensate from the low and the high stage compressors has not been changed.

The cost of installing the absorption equipment was about $800, and no extra expense is incurred for operation except the small cost of upkeep. The profit resulting with the present price of gasoline (May, 1919) varies from $52.60 to $84.40 per day. This figure is

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based solely on increase in production, and does not take into consideration the increase in value of the naphtha by raising its gravity from 50–51° B. to 58–59° B. The product is sold in the vicinity to garages and makes a splendid motor fuel.

PLANT 2.

At plant 2, also situated in the Bartlesville field, a two-stage expansion engine and double-pipe coils are installed. The gas is expanded from 275 pounds per square inch to 5 pounds per square inch, and the high-pressure gas is cooled to 35° F. During July and August of 1918, the average production made by this arrangement was 923 gallons per day, and still the residual gas contained 0.200 gallon per 1,000 cubic feet.

PLANT 5.

At plant 5 (Bartlesville field) part of the residual gas was run through an 18 inch by 20-foot tower which was filled with crushed rock. Naphtha was used as an absorption menstruum and passed continuously through the absorber; the gravity was increased from 52° to 59° B. The gasoline content of the residual gas passing through the absorption tower was lowered from 0.336 to 0.140 gallon per 1,000 cubic feet.

The condensate at this plant is blended to make a product with a gravity of 67° B. During one week when the absorption tower was not in use 2.68 gallons of raw compression gasoline to one gallon of naphtha was required to obtain a 67° B. blend. On the following week the absorption tower was used and only 2.26 gallons of raw condensate to one gallon of naphtha was necessary in order to procure the same gravity. The temperature during the two weeks in which these tests were run averaged 80° F. and 79° F., respectively.

Results of weathering tests on the product made in the blending tower and that made by blending naphtha and compressor condensate are shown in Table 4 following:

TABLE 4.—*Weathering losses of stock blended in absorption tower and of that blended with compressor condensate, plant 5.*

Date (1918).	Time.	High product (compressor).		Blended product (absorption).	
		Quantity taken for test.	Gravity.	Quantity taken for test.	Gravity.
		C. C.	*°B.*	*C. C.*	*°B.*
July 17	4.40 p. m.	550	57.7	550	67.5
18	9.30 a. m.	500	55.0	490	53.9
19	10.00 a. m.	480	54.1	468	52.1
20	10.00 a. m.	468	53.8	457	51.8
21	11.00 a. m.	450	63.3	445	51.2
22	4.30 p. m.	444	52.4	435	51.0
23	5.00 p. m.	440	52.4	430	50.8
24	4.00 p. m.	425	52.4	425	50.6
28	6.00 p. m.	405	51.8	405	50.0
Aug. 1	4.15 p. m.	390	51.6	390	49.8

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Attention is called to the low gravity of the absorption stock, which is saturated with the so-called "permanent gases" that increase the gravity and weather more rapidly than the liquid fractions that would have been absorbed to a larger degree provided less naphtha had been circulated and more efficient baffling material installed. Distillation curves for this product are shown in figure 5.

The blending tower used at this plant is shown in Plate I, *A*. The tower is too small to handle all the gas compressed at this plant; besides it is filled with crushed rock which is an inefficient baffling ma-

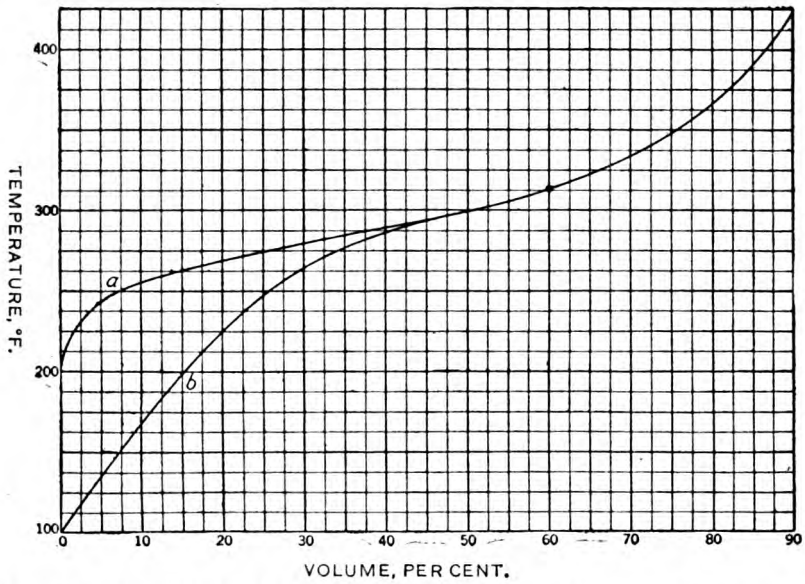

FIGURE 5.—Distillation curves for naphtha and blended stock from absorber, plant 5. *a* Naphtha, *b*, blended product.

terial and lowers the tower's gas capacity. Plate I, *B*, shows a set of vertical absorption towers that are handling 800,000 cubic feet of gas daily.

PLANT 26.

Plant 26 (Cushing field) is equipped with the absorption system to treat the residue gas. The gas passes through nine horizontal absorbers, each 16 inches by 40 feet, which are connected in three parallel sets of direct absorbers in series. "Mineral seal oil" is used for the absorption menstruum. The oil is introduced through sprays in the top scrubber, then passes down into the next absorber, where the gas is first treated by being allowed to bubble up through the oil. The arrangement is shown in Plate II. The residual gas, at the intake on the absorbers, contains 0.130 gallon per 1,000 cubic feet, and is cleaned to a content of 0.028 gallon. It is doubtful whether this ab-

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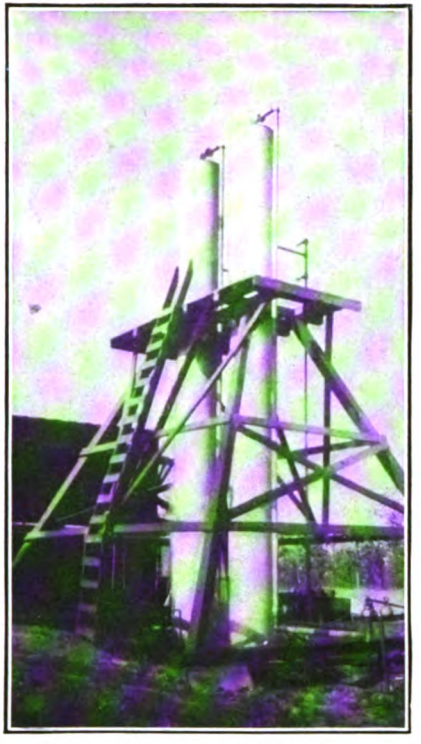
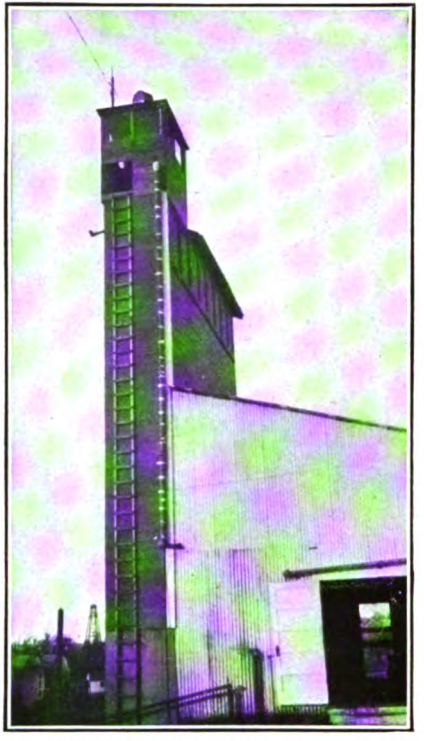
A. ABSORPTION TOWER TREATING RESIDUAL GAS.



B. ABSORBER TREATING RICH GAS.



C. REFRIGERATION AND ABSORPTION SYSTEM COMBINED.

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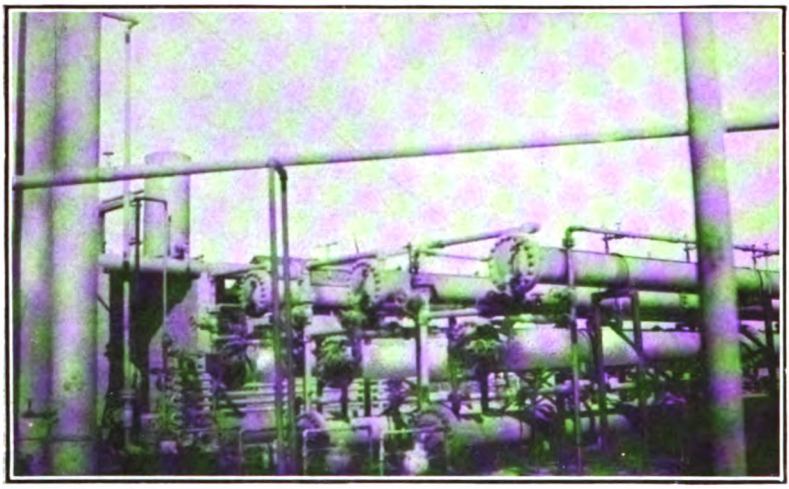

A. HORIZONTAL ABSORBERS WORKING ON RESIDUAL GAS.

B. SCRUBBERS WORKING ON RICH GAS.

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sorption installation is a profitable investment, as the initial cost was extremely high, and the gasoline content of the residual gas is abnormally low because of the efficient cooling system of the compression plant and the character of the gas being treated.

PLANT 28.

Plant 28 (Cushing field) is equipped with a combination absorption and refrigeration process to recover the gasoline from the residue gas. The naphtha is cooled by an ammonia expansion system to 35° F. and pumped into vertical absorbing towers, 18 inches by 30 feet in size, through which the residual gas flows. The towers are insulated by cork and boxed as shown in Plate I, *C*. The residual gas discharging from these towers contains 0.15 gallon of gasoline per 1,000 feet. The pressure maintained on the absorbers is 250 pounds.

The writers are indebted to Lloyd F. Boyer for the following description of the method of operating this plant:

> The residual gas from the top connections of the high-pressure accumulators of the regular compression plant is cooled in vertical towers by direct contact with chilled gasoline. Gasoline is thus condensed directly into that used as the cooling agent and the blended mixture flows by gravity from the bottom of the tower into a separating tank. Here the condensed water is removed. The high-pressure circulating pump takes its suction from the gasoline in this tank and discharges gasoline through the double-pipe ammonia expansion coils and then into the sprays in the tower. Thus a certain quantity of gasoline is condensed in the tower, tending to increase the quantity in the system, the excess overflows into the accumulator tank, from which it is drawn into storage. Distillate for blending is pumped into the system continuously at the proper rate to maintain the desired gravity of the product.
>
> The gas is treated under usual compression pressure, approximately 250 pounds per square inch. It passes through the towers only once, as the towers are connected in parallel. The refrigeration equipment is of the usual compression type using single-acting two-cylinder York compressors and Shipley flooded condenser. The double pipe coils are of 2-inch and 3-inch pipe, the gasoline flowing through the inner pipe. The return bends are extra heavy to withstand the high pressure.
>
> During the summer months—that is, April to October, inclusive—the additional yield from the refrigeration system measured in the storage tanks upon the basis of the original gas taken into the compression plant was 0.046 gallon per thousand. Of this 0.26 gallon per thousand was shipped in the cars, the difference being lost in weathering and loading.
>
> When the system was originally started we used calcium chloride brine as the cooling agent. The mixture of brine and condensate was separated by difference in gravity and the brine was continually circulated. However, so much trouble developed in clogging of piping, freezing, and discoloration of product that we abandoned that method.

All of the compressor condensate from this plant is blended to a gravity of 61 to 63° B. The storage tanks, shown in Plate V, *B* (p. 32) are connected to the intake of one of the compressors, and the vapor which is ordinarily lost while weathering is compressed to

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200 pounds, which gives very remunerative results. The average daily production of this plant is 9,000 gallons from field gas, 1,000 gallons absorption gasoline from residue, and 2,800 gallons representing compressed vapors from weathering tanks.

LOSSES IN RESIDUAL GAS.

The average loss of gasoline in residual gas at the compression plants tested, as shown in Table 2 (p. 12), is 0.337 gallon per 1,000 cubic feet of gas. The losses at various temperatures and pressures by actual absorption tests approximately agree with the theoretical calculations shown in figure 1 (p. 6), and Table 1 (p. 9). These calculations, however, are not intended as a criterion by which to arrive at the gasoline content of any particular residual gas, but are useful in forming a preliminary estimate.

FIELD DATA ON ABSORPTION PLANTS.

Data collected on the gasoline content of the residual or discharge gas from absorption plants are recorded in Table 5 following.

TABLE 5.—*Field data, absorption gasoline plants in Oklahoma.*

Item.	Bartlesville field.	Cushing field.	Osage field.
Capacity, M cubic feet	375	300	12,000
Production, gallons per day	800	800	1,750
Recovery, gallons per M cubic feet	2.1	2.66	.146
Absorption medium	(a)	(a)	(a)
Temperature of still, °F	243	210	209
Pressure in still, pounds per square inch	10	(b)	(b)
Kind of absorbers	(c)	(d)	(e)
Pressure on absorbers, pounds per square inch	80	5	225
Oil circulated, gallons per M cubic feet	77	134	4.9
Temperature of oil (entering absorbers), °F	75	80	90
Atmospheric temperature (during test), °F	69	45	78
Gasoline in residual gas, gallons per M cubic feet	0.054	0.35	0.034
Percentage of recovery	97	87	81

a "Mineral seal oil."
b Atmospheric.
c Horizontal and vertical.
d Vertical cap and bell.
e Vertical.

The losses are much lower than those of compression plants, as it is possible to discharge much leaner gas from these plants than from plants using the compression and cooling process. An absorption system requires more careful attention, but the various factors affecting recovery are not especially difficult to understand. Vigilant attention to plant operation will be more than compensated by the increased recovery.

EXPANSION ENGINES.

Some plants use an expansion engine for recovering gasoline in residual gas. The apparatus and procedure by which this is accomplished vary somewhat in different plants, but all are based on the

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fundamental principle of absorbing the power (and consequently the heat) stored in the compressed gas by causing the gas to perform work. Expansion under these conditions results in much lower temperature than would otherwise be obtained. The gas from the high-pressure accumulators, after passing through the inner tubes of double-pipe coils, is admitted to the expansion cylinder of the expander-compressor at full high-stage pressure. The expanded gas is exhausted, against a back pressure of 5 to 20 pounds per square inch, between the outer and inner tubes of the double-pipe coils, where it serves to cool the compressed gas within the inner tubes. The power developed in the expansion engine is used to compress additional gas. Most of the recent installations use two-stage expanders. These are so arranged as to exhaust the first-stage expanded gas into double-pipe coils where the gas is warmed before going to the second-stage cylinder.

By expanding the gas in two stages the temperature drop in each cylinder is much less than in the single-stage type, and the engine gives less trouble from condensation and freezing of water vapor, thus permitting more effective interchange of heat.

The expansion engines are perhaps the most troublesome feature of such gasoline plants as use them. Difficulties arise from the high initial pressure of the gas, the extremely low exhaust temperatures, and the condensation of moisture and gasoline with the resultant freezing, which makes internal lubrication of valves and cylinders exceedingly difficult. It has been found that by using glycerin in very small quantity as a lubricant, and applying it directly to the rubbing surfaces, the machine can be operated almost continuously.

W. R. Finney of the Midwest Refining Co. has found that in addition to glycerin, ordinary flake graphite mixed with zero cold test oil is a highly efficient lubricant for expansion engines. He also uses brass plates that fit on the steam parts of the expansion cylinders. These plates take all the wear and are easily replaced.

All these difficulties can be overcome by using a rotary expansion engine[a] or spiral turbine. The gas passes around the spaces between teeth and causes the gears to rotate. The turbine is directly connected to a centrifugal pump which circulates the water for the cooling towers.

A great many compression plants have constructed double-pipe tubes in which the high-pressure gas expands through a nozzle or valve. Almost without exception the cooling effect is so small as to give practically no precipitation of gasoline. The impracticability of expanding gas adiabatically through a nozzle is well understood;

[a] Staunton, W. F., Casing-head gasoline plant: Mining and Oil Bull., vol. 4, March, 1918, p. 143.

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it is never possible to effect any great reduction in temperature by such means. In order to obtain a decided lowering in temperature the expanding gas must be forced to do mechanical work.

Undoubtedly the use of expansion engines for recovering gasoline from the residual gas is profitable at most plants where they have been put in, but the troubles arising from mechanical difficulties and from the high vapor pressures and large weathering losses of the "wild" condensate have made operators reluctant in constructing such installations.

THE REFRIGERATION PROCESS.

Some plants have used the ordinary ammonia refrigeration machine for recovering gasoline from the gas discharged from the compression plant. This system consists essentially of three parts—a refrigerator, a compression pump, and a condenser. The refrigerator, which consists of a coil or a series of coils, is connected to the suction side of the pump, and the delivery from the pump is connected to the condenser. Brine cooled by the expansion of the ammonia passes through double-pipe coils, cooling the residual gas. The compressed ammonia vapor is condensed by cooling in water condensers, the liquid ammonia returning by the regulating valve to the refrigerator.

Recently considerable work has been done on the application of mechanical refrigeration to the recovery of natural-gas gasoline. The most improved methods used are the direct contact processes, using sodium chloride brine, calcium chloride brine, or gasoline as the refrigeration medium.

DIRECT-CONTACT BRINE METHOD.

In this method, the gas to be treated is introduced into the bottom of a vertical tower fitted with suitable baffling material. Over these baffles is sprayed the refrigeration liquid, such as salt brine or calcium chloride brine. The brine showering downward comes in direct contact with the gas rising countercurrent to it, efficiently cooling the gas. The gasoline condensed is carried down with the brine. The mixture is led into a separator where the gasoline rises to the top and is trapped off; the brine is pumped back through the brine cooler to the scrubber. The water vapor in the gas causes gradual dilution of the brine, which must be concentrated in vats by steam coils; also there is opportunity for freezing of liquid on the baffles. To overcome these disadvantages, gasoline is sometimes used as the refrigerative agent.

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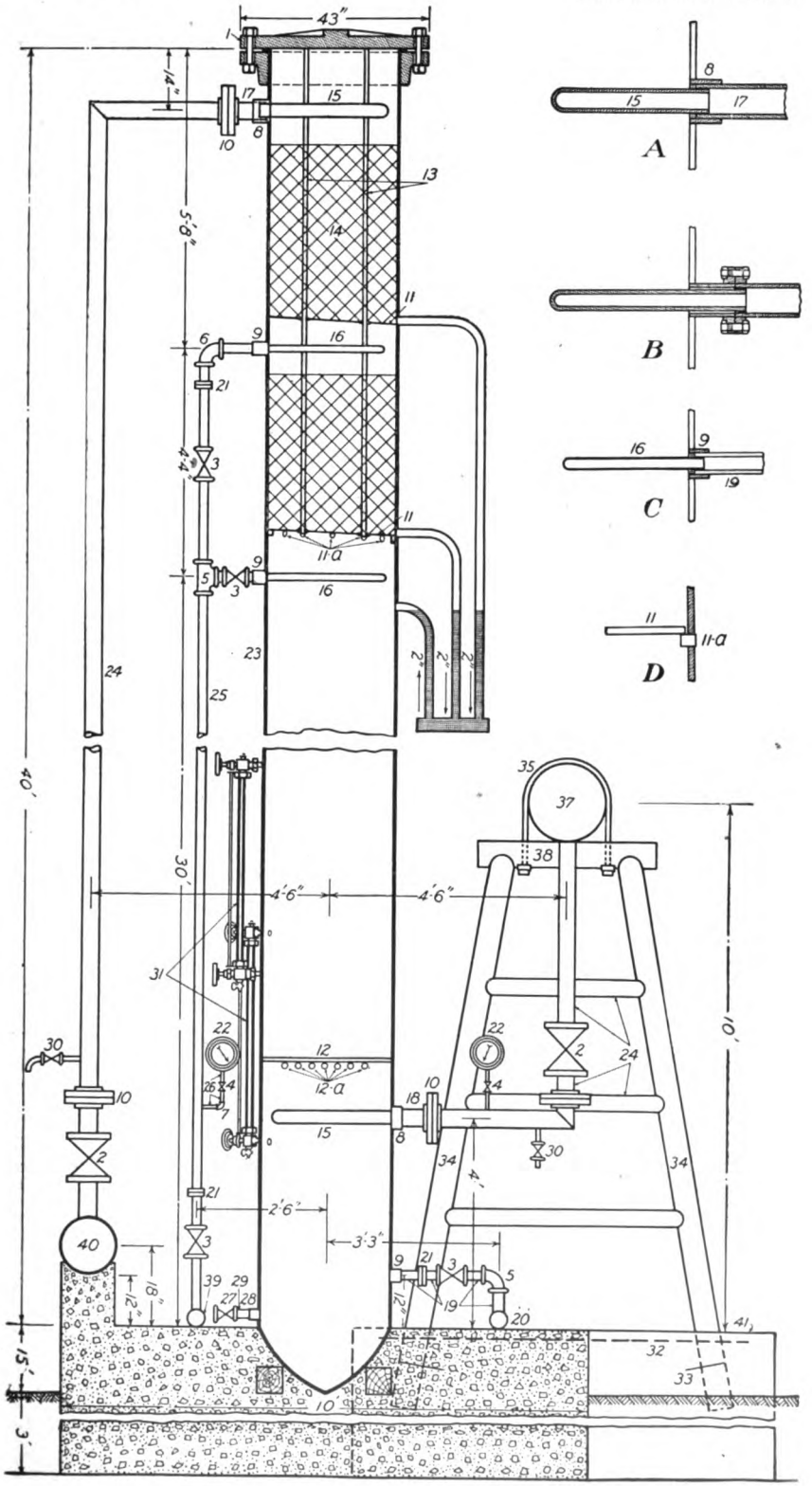

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DIRECT-CONTACT GASOLINE METHOD.

This method is very similar to the brine method, except that gasoline is used as the refrigerant, and the increase in volume is trapped to storage or blending tanks. The layout of such an installation is shown in Plate III. Two towers are installed, and these are used alternately in case water freezes on the baffles of either tower. If such freezing occurs the gas and gasoline are by-passed to the other scrubber and warm compressed ammonia, instead of the expanding ammonia, is lead into the coils in the tower to thaw the ice.

A plant of this type in Osage County, Okla., treating the residual gas from the compression plant, gave the following results for the month of September:

Operating pressure, pounds per square inch	250
Temperature of gas, ° F	20
Average daily production of refrigeration plant, gallons	310
Average daily production of compression plant, gallons	2,000
Average volume of gas treated daily, cubic feet	706,316
Average daily recovery from residue gas, gallons per M cubic feet	0.44

The great advantage of the refrigeration process is that the chilled condensate weathers more slowly, and this permits a sharper separation between the permanent gases dissolved and compressed into the condensate and the liquid fractions. The cold product, if it is permitted to warm up slowly, will gradually liberate the dissolved gases and "wild" fractions, but this effect will be negligible if large storage tanks are used. The disadvantages are the initial costs, cost of operation, and possibility of losing ammonia, which is especially true when the corrosive water typical of oil fields is used over the cooling coils. Detailed descriptions of plants in California using this system are given in Bulletin 151[a] of the Bureau of Mines.

REFRIGERATION APPLIED TO THE ABSORPTION PROCESS.

Probably the brightest future for refrigeration methods in treating natural gas for gasoline is in their application to the absorption process. It is undoubtedly beneficial to cool the absorbing menstruum, for a large number of plants use oil at temperatures too high to obtain complete recovery. As is shown in a later paragraph, oil of any given temperature can not be trusted to collect and absorb any great quantity of the gasoline fractions having boiling points below the temperature of the oil itself. Not infrequently oil is found entering the absorption towers at 100° F. even in cool weather. By cooling the absorption medium the plant may be run at much higher satura-

[a] Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration. Bull. 151, Bureau of Mines, 1918, pp. 63–66.

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tions, with the obvious advantages of using less oil in the system—resulting in low steam consumption and permitting smaller plant equipment—and causing easier distillation, with the end point of the distilled product invariably lower. By using artificial cooling the working of the plant becomes independent of climatic temperature conditions and is more flexible, as one of the variable factors has been reduced to a constant.

OPERATION OF ABSORPTION PLANTS TREATING RESIDUAL GAS.

For all plants vertical towers are recommended in preference to horizontal absorbers. The merits of the vertical absorbers are higher efficiency, less circulating oil, higher saturation of absorbing medium, and lower initial and operation costs. Recovery efficiencies as high as 95 per cent are possible with vertical scrubbers, the recovery being taken, as determined by the small portable absorbers, as 100 per cent.

TOWERS.

Details of typical absorption towers are shown in figures 6, 7, 8, and 9, Plate IV (p. 30). The towers vary in diameter from 12 to 36 inches, and the height should not be less than 30 feet. In a recently designed plant, the absorbers are 42 feet high and practice is tending toward higher towers. Factors regulating the size of the absorbers are pressure, flow velocity of gas, and temperatures of oil and gas. Diameters of absorbers should be such that the linear velocity of gas should not exceed 75 feet per minute in the unbaffled part of the towers. [a]

Figure 6 shows in elevation the blending tower of a casing-head gasoline plant. The tower is 15½ inches in diameter and 21 feet high. A bill of the material used in constructing an absorber of this type, and a detailed explanation of the lettering on the figure, are presented on the page opposite figure 6.

Figures 7 and 8 show details of an installation of three vertical absorption towers. Figure 7 shows the plan of the towers with piping and connections; figure 8, the end elevation of one of the towers.

The writers are indebted to W. R. Finney for the design of blending tower shown in figure 7. Since making this design, he has suggested the following alterations: The use of the spiral spray in the place of a plain perforated nipple for introducing the absorbing medium, a drain in the runback from the plate, and lowering the inlet so as to get bubbling contact if desired.

Still another vertical tower is shown in Plate IV.

[a] Dykema, W. P., Recent developments in the absorption process for recovering gasoline from natural gas: Bull. 176, Bureau of Mines, 1919, p. 26.

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BAFFLES.

Paramount in importance is the proper choice of a suitable baffling material or tower packing. The factors to be considered in determining what material shall be used are surface exposed by the packing, weight per unit volume, voidage, likelihood of channeling, and whether the material will have any deleterious effects on other working parts of the plant. For example, rust or wood splinters may get into the traps and valves, or finely divided dust may get into the absorption medium and foster the formation of oil-water emulsions, which are sometimes troublesome and difficult to handle.

Some factors (average) of typical tower packing are recorded in Table 6:

TABLE 6.—*Approximate factors for representative baffling material.*

Material.	Weight per cubic foot.	Surface exposed per cubic foot.	Voidage.
	Pounds.	*Sq. feet.*	*Per cent.*
Raschig rings	35	60	70
Clay tubes, 4-inch by 3-inch	112	32	35
Steel shavings	57	.....	.....
Crushed rock	100	.....	.....
Lathing	15	22	69

Steel shavings give a large voidage and large surface exposed, but have the disadvantages of rapid settling, easy corrosion (especially with casing-head gas, which sometimes contains as much as 50 per cent air besides some salt water), and tendency to be carried into the traps, the valves on pipe lines, and the valves in the pumps.

In using any tower packing from which small particles are apt to become detached, screens should be placed in the oil lines at a number of places to protect the pump valves and to clean the oil before it enters a pipe or tank in which the flow velocity is reduced, otherwise the particles will settle and accumulate.

Crushed rock should not be used, as the voidage is too small. One tower filled with steel shavings will handle more gas than two filled with rock.

One company in the Mid-Continent field is using curved partition rings of vitrified clay, 4-inch by 3-inch, such as are used extensively in the acid and alkali industries. This packing has the same disadvantages as the crushed rock in giving small free passage for gas; in addition the rings can not be placed in the tower at random without forming free spaces through which channeling will take place and prevent the oil and gas being brought into intimate contact.

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Bill of material used in absorber shown in figure 6.

[Reference numbers are same as in fig. 6.]

Reference No.	Quantity needed.	Article.	Material.
1	1	Van Stone type cover (for 16-inch pipe)	Cast iron.
2	1	1-inch, extra-heavy, screw gate-valve	Brass.
3	1	¾-inch, extra-heavy, screw gate-valve	Do.
4	1	½-inch standard screw gate-valve	Do.
5	4	2-inch, extra-heavy, screw ell	Manganese iron.
6	2	1-inch, extra-heavy, screw ell	Do.
7	1	1-inch, extra-heavy, screw tee	Do.
8	1	¼-inch, extra-heavy, screw ell	Do.
9	3	2-inch, ground-joint, Navy lip union	Do.
10	2	1-inch, ground-joint, Navy lip union	Do.
11	3	2-inch, extra-heavy, screw collar	
12	1	1-inch, extra-heavy, screw collar	
13	4	2 by 12 inch standard pipe nipple	
14	4	2 by 6 inch standard pipe nipple	
15	2	1½ by 12 inch nipple, welded end	
16	1	½ by 12 inch nipple, welded end	
17	4	1 by 6 inch standard pipe nipple	
18	1	¾ by 4 inch standard nipple	
19	1	¼ by 3 inch standard nipple	
20	1	2 to 1 inch by 12 inch, extra-heavy, swing nipple	
21	2	½ by 15 inch (outside diameter) plate	
22	2	¼ by 15 inch (outside diameter) plate	
23	1	Joint of 15½-inch, 70-pound, casing	
24	[a] 35	2-inch standard pipe	Black wrought iron.
25	[a] 50	1-inch standard pipe	Do.
26	1,000	Circular tile	
27	[a] 10	1-inch rod	Iron.
28	16	⅜-inch hexagonal set screws	
29	1	5-inch pressure gage (zero to 500-pound pressure)	
30	2	Extra-heavy, 36-inch gage	
31	1	1½-inch welded seal	
32	4	¾-inch rod 3 feet 1 inch long	

[a] Feet.

Explanation of lettering shown on figure 6.

A, Detail of gasoline inlet, same for gas outlet; *B*, detail of naphtha inlet; *C*, detail of method for holding perforated plates in place. (Parts are numbered as in table above.) *1*, Cover plate; *2*, 1-inch gate valve (not shown); *3*, ¾-inch gate valve for water drain; *4*, ½-inch gate valve; *5*, 2-inch ell; *6*, 1-inch ell; *7*, 1-inch tee, *8*, ¼-inch ell; *9*, 2-inch union; *10*, 1-inch union; *11*, 2-inch collar, welded; *12*, 1-inch collar, welded; *13*, 2-inch by 12-inch nipple (not shown); *14*, 2-inch by 6-inch nipple; *15*, 1½ by 12 inch perforated nipple, with welded end, four rows of ¼-inch holes, 16 in row, ½-inch pitch, drilled in bottom of nipple; *16*, ½-inch by 12-inch perforated nipple with welded end, two rows of ¼-inch, 8 in a row, ½-inch pitch drilled in bottom (perforated nipples are welded to outside pipes and inserted through screwed collar); *17*, 1-inch by 6-inch nipple (not shown); *18*, ¾-inch by 4-inch nipple (not shown); *19*, ¼-inch by 3-inch nipple (not shown); *20*, 2 by 1 by 12-inch swing nipple at gasoline outlet; *21*, 15-inch perforated plates, ½-inch thick, lower plate drilled with one hundred and twenty 1-inch holes, upper plate, four hundred and eighty ½-inch holes; *22*, 15-inch plate, ¼-inch thick, welded to rods; *23*, 15½-inch casing; *24*, 2-inch pipe; *25*, 1-inch pipe; *26*, tile; *27*, 1-inch rods, welded; *28*, set screws (not shown); *29*, pressure gauge, 500-pound pressure; *30*, gages; *31*, welded seal (not shown); *32*, ¾-inch rods; *33*, 1-inch lug, welded.

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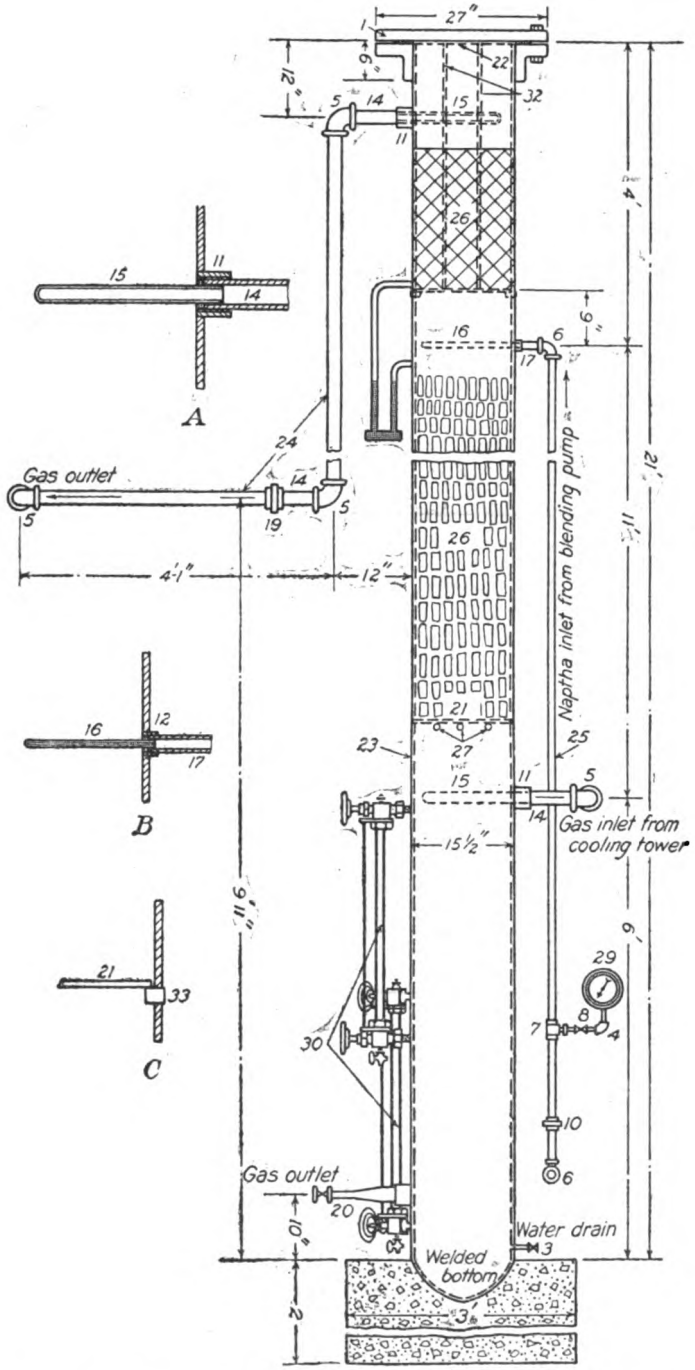

FIGURE 6.—Blending or absorption tower for casing-head gasoline plant.

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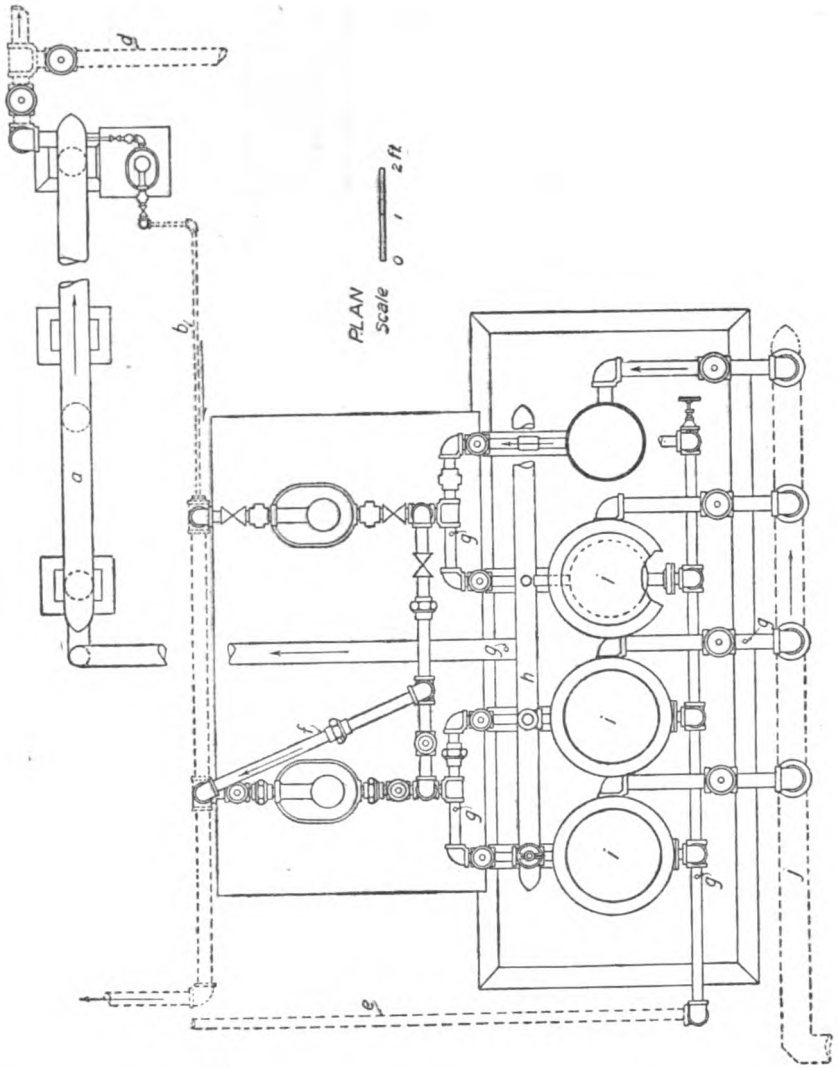

FIGURE 7.—Plan of absorption towers showing piping and connections. *a*, Gas traps, 400-pound pressure; *b*, 3-inch line to tank, 50-pound pressure; *c*, ¾-inch line from trap; *d*, 3-inch by-pass, 400-pound pressure; *e*, 2-inch oil line, 400 pounds; *f*, 2-inch by-pass; *g*, thermometer wells; *h*, 4-inch gas header, 400 pounds; *i*, absorption towers, 400 pounds; *j*, 6-inch gas header, 400 pounds. (For elevation see fig. 8.)

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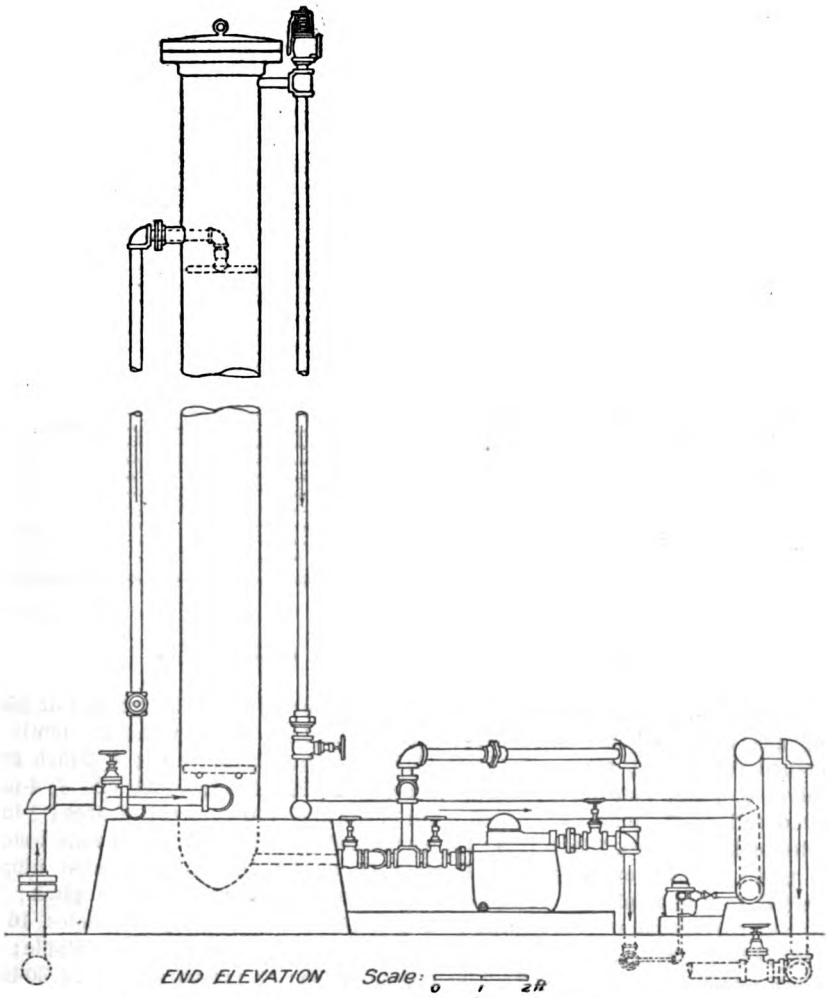

FIGURE 8.—End elevation of installation shown in figure 7.

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Bill of material for absorber shown in Plate IV.

[Reference numbers are same as in Pl. IV.]

Reference No.	Quantity needed.	Article.	Material.
1	1	Van Stone type cover	
2	2	4-inch xtra heavy screw gate-valve	
3	4	2-inch xtra heavy screw gate-valve	Brass.
4	2	¼-inch standard screw gate-valve	Do.
5	1	2-inch extra heavy screw tee	Manganese iron.
6	2	....do	Do.
7	1	¼-inch standard screw ell	Do.
8	2	¼-inch extra heavy screw collar	Do.
9	3	2-inch extra heavy screw collar	Do.
10	8	4-inch by 1½-inch extra heavy collar	Do.
11	2	¼-inch by 29½-inch (outside diameter) perforated plate	Steel.
12	1	½-inch by 29½-inch (outside diameter) perforated plate	Cast iron.
13	*a* 37	1-inch rod	Iron.
14			
15	2	3½-inch by 26-inch welded nipple	
16	2	1½-inch by 26-inch welded nipple	
17	4	4-inch by 6-inch pipe nipple	
18	2	4-inch closed nipple	
19	8	2-inch by 6-inch pipe nipple	
20	4	2-inch closed nipple	
21	4	2-inch extra heavy flange union	
22	2	5-inch pressure gage (pressure, zero to 500 pounds)	
23	1	Joint of 30-inch pipe	
24	*a* 75	4-inch standard pipe	
25	*a* 60	2-inch standard pipe	
26	5	¼-inch by 3-inch pipe nipples	
27	1	Extra heavy screw gate-valve	Brass.
28	1	Extra heavy screw collar	
29	1	1-inch by 4-inch pipe nipple	
30	2	1-inch extra heavy sample gate-valve	
31	2	42-inch extra heavy gages	
32	14	¾-inch reinforcing bars 8 feet long	
33	14	¾-inch rod 2 feet long	
34	7	Pipe support, 6-inch by 4-inch welded pipe	
35	7	1-inch U-bolts, with nuts and washers	

a Feet.

Explanation of lettering shown on Plate IV.

A, Detail of gas-inlet and gas-outlet connections; *B*, alternate method of making gas inlet and gas outlet; *C*, detail of oil-inlet connection; *D*, detail of method for holding plate. *1*, Cover plate; *2*, 4-inch gate valve; *3*, 2-inch gate valve; *4*, ¼-inch gate-valve; *5*, 2-inch tee; *6*, 2-inch ell; 7, ¼-inch ell; *8*, 4-inch screw collar; *10*, union; *11*, ¼-inch plate perforated (50 per cent of area) ½-inch holes or larger; *11a*, 1-inch lugs; *12*, perforated plate; *12a*, 7 1-inch rods welded to pipe; *13*, supporting rods; *14*, tile; *15*, 3½ by 26-inch perforated nipple, welded to 4-inch pipe, 4 rows of ½-inch holes, 16 in row, 1½-inch pitch; *16*, 1½-inch perforated nipple welded to 2-inch pipe; 2 rows of ⅜-inch holes, 16 in row, 1½-inch pitch; *17*, 4-inch by 6-inch pipe nipples; *18*, 4-inch close nipple; *19*, 2-inch by 6-inch pipe nipple; *21*, 2-inch flange union; *22*, pressure gage; *23*, 30-inch casing; *24*, 4-inch pipe; *25*, 2-inch pipe; *26*, ¼-inch by 3-inch nipple; *27*, 1-inch gate-valve; *28*, 1-inch collar; *29*, 1-inch by 4-inch nipple; *30*, sampling valve; *31*, gages; *32*, ¾-inch reinforcing rods, 8 feet long; *33*, ¾-inch bars, 2 feet long; *34*, leg of supports; *35*, 1-inch U bolts; *36*, gas meter on main line (not shown); *37*, 18-inch headers, supported at intermediate points by pipe columns, spaced 10 feet apart; *38*, support for header; *39*, oil meter on main line; *40*, header; *41*, concrete base for pipe support.

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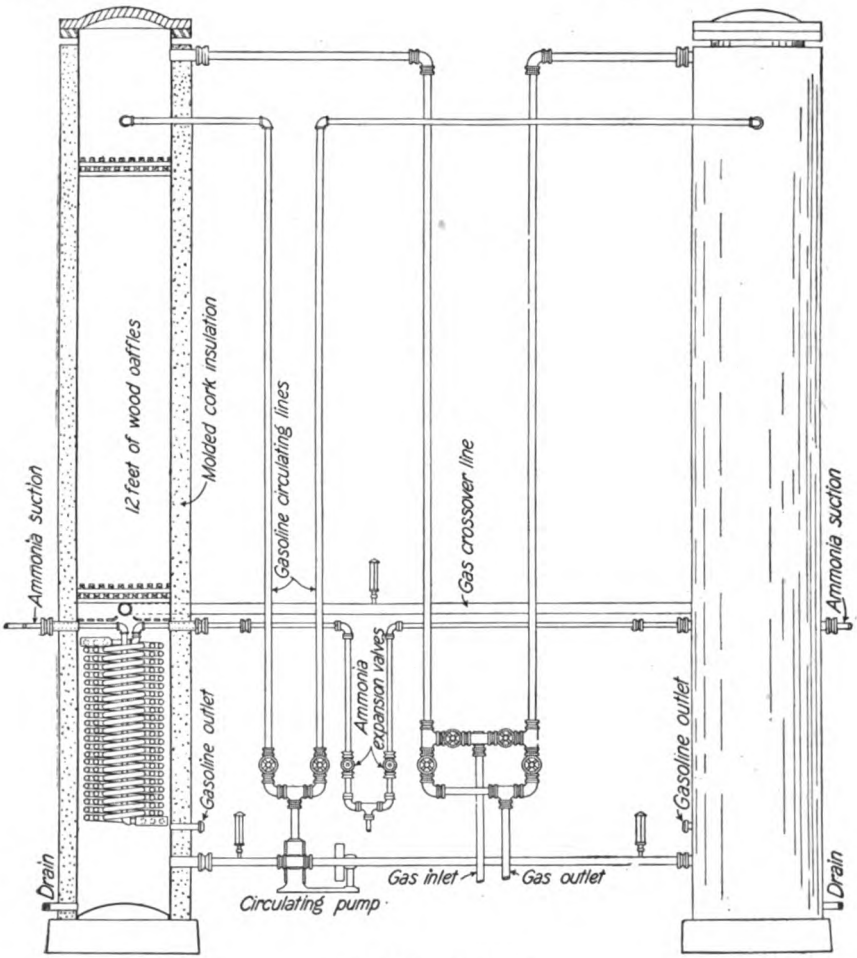

A VERTICAL ABSORBER.

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Wooden lathes have proved successful in many plants and are very efficient if care is taken in their construction. The baffling is usually made of latticework. All the boards should be planed in order to eliminate any possibility of splinters getting into the traps or valves. Attention should be given to the design in order that the oil will not channel, particularly around the edges of the tower.

A plant in Louisiana uses three baffle plates welded into the tower, the plates being perforated with $\frac{1}{64}$-inch holes in place of any of the usual packing materials. The perforations allow less than 50 per cent of the cross-sectional area for the passage of gas, causing a high flow velocity. Great trouble is encountered from loss of oil in a fine spray, most of which can not be caught by any separator or drip that has been installed. The small holes break the oil into small drops, giving a spray effect and practically atomizing the oil, in which state it can not again be collected and separated from the gas.

Raschig rings seem to be the best tower packing that has been examined. They are made of glazed clay, 1 inch long and 1 inch in diameter, have walls one-eighth inch thick, and weigh only 35 pounds per cubic foot. They give 60 square feet of exposed surface per cubic foot with 70 per cent voidage, and can be thrown into the tower at random without forming free or large open spaces which allow channeling.

RATES OF OIL FLOW.

The proper quantity of oil to circulate will depend on the gas pressure, temperature of oil, mechanical arrangement of absorber and baffling material, and the characteristics of the particular gas to be treated, which can not be overlooked.

With all plants a smaller quantity of oil is required in a vertical tower than in horizontal absorbers, also less oil is required in high (40 to 50 foot) towers than in short (18 to 30 foot) towers.[a] The more uniformly the oil is distributed and the more surface there is exposed, the smaller will be the amount of oil necessary for efficient recovery of the lighter hydrocarbons, and this must be borne in mind when choosing a tower packing.

On account of the different characteristics of each individual gas, no table can be compiled that will accurately give the quantity of oil in gallons to be circulated per 1,000 cubic feet of gas. The volume of oil that it is necessary to circulate for complete recovery of the gaso-

[a] For discussion of height of towers see Bulletin 176, Bureau of Mines, "Recent developments in the absorption process for recovering gasoline from natural gas," by W. P. Dykema, 1919, p. 25.

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line in the gas depends upon the pressure of the gas and the gasoline content. For example, two gases in southern Kansas each contain approximately 0.20 gallon of gasoline per 1,000 cubic feet of gas. When these gases are treated in exactly the same vertical absorber and at the same pressure, the saturation of the absorption menstruum can be permitted to rise as high as 9 per cent with one of them whereas with the other gas the efficiency of recovery decreases after the saturation of the oil passes 4 per cent.

One should endeavor so to regulate the quantity of oil circulated as to obtain highest saturation that gives the maximum economic efficiency in treating the gas. With treated absorption oil of high gasoline saturation, the cost of distillation is less and a better product is made, particularly as regards the end point and the color.

OPERATION OF STILLS.

There are two types of stills in general use in the absorption practice. One contains a large quantity of oil which is heated by steam from open coils entirely, or from a combination of open and closed coils. Various systems of baffling are used in order to direct the flow and to lengthen the time that the oil remains in the still. The other type contains a series of pans filled with closed coils into which the oil being treated flows; only a small amount of oil is maintained in the bottom of the still and this is heated by direct or open steam. The capacity of this still arrangement is very large as compared with the other type of "tub" still. An ordinary still constructed so that oil can be heated by direct and closed coils is shown in Plate V, *A*. For detailed information regarding the construction of stills, the reader is referred to Bulletins 176[a] and 120[b] of the Bureau of Mines.

Troubles may be experienced in applying absorption to the residual gas from compression plants if "mineral seal oil" is used as the absorption medium instead of naphtha, the usual absorbent encountered in absorption practice. The residual gas contains large quantities of propane and butane, which are permanent gases under ordinary atmospheric conditions, but will dissolve readily in the absorption medium. On distillation the dissolved gases will be liberated and carry with them liquid hydrocarbons, resulting in a loss of stable gasoline at the "look box." Regardless of how cold the condensers may be, the permanent gases will carry away some of the gasoline. However, the colder the condenser the lower will be the partial vapor pressures of the liquid components that govern the quantity of gasoline in the tail-house vapors.

[a] Dykema, W. P., work cited.

[b] Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas, 1917, pp. 46–59.

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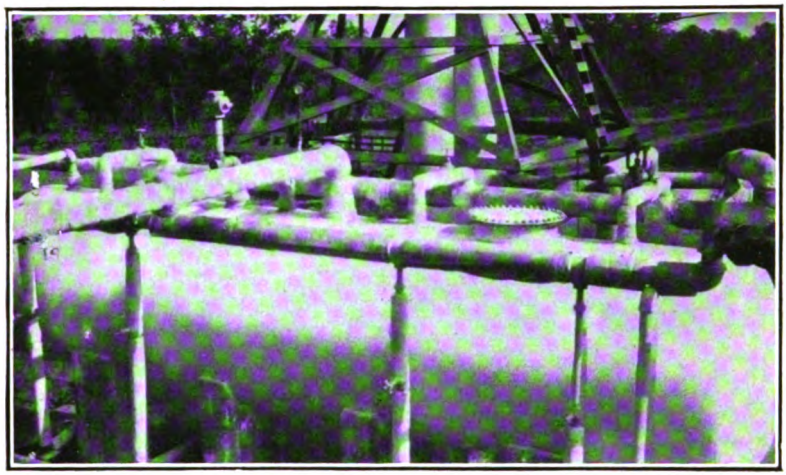
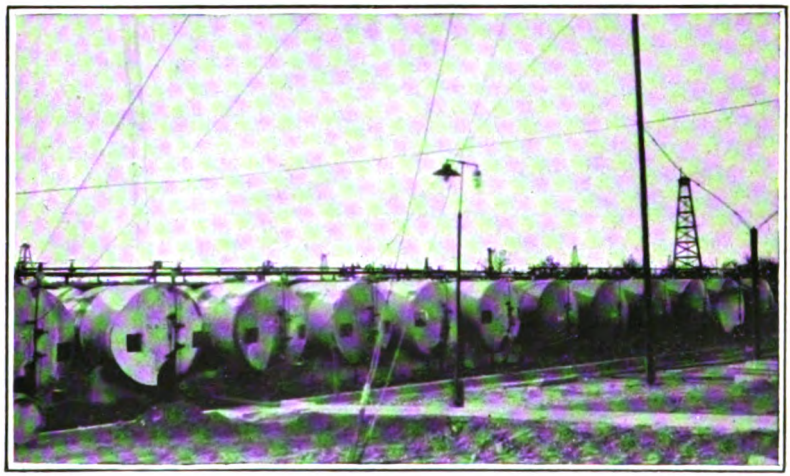


A. TYPICAL STEAM STILL FOR STRIPPING ABSORPTION OIL.



B. STORAGE TANKS FROM WHICH VAPORS ARE RECOMPRESSED.

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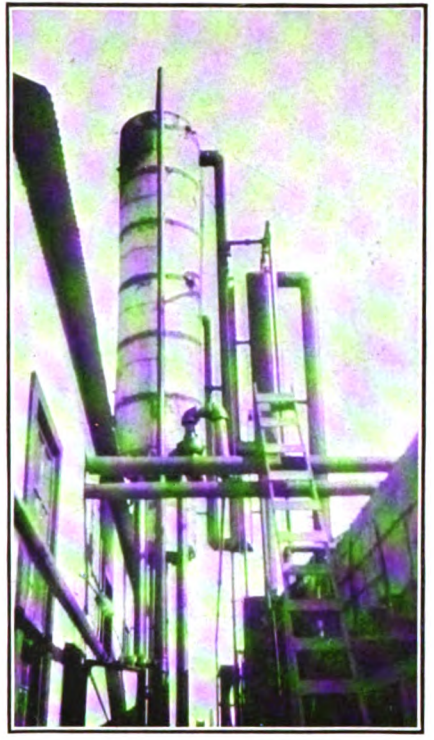
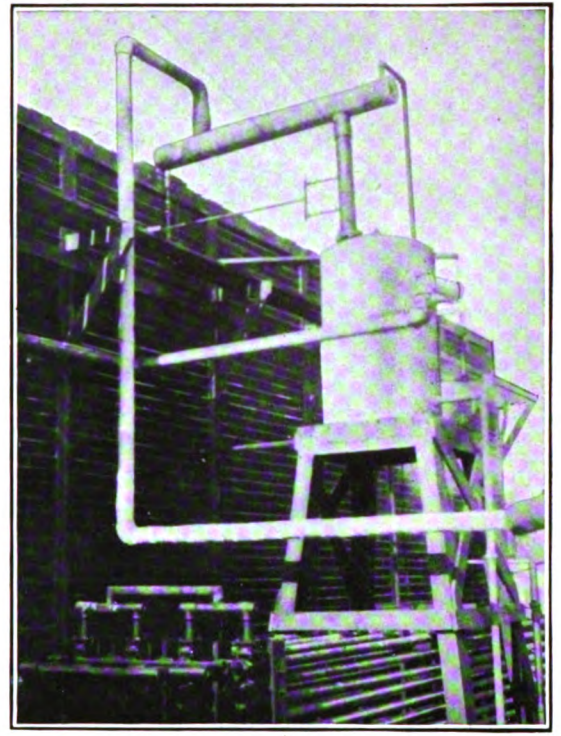
A. "KNOCK-OUT" BOX WITH THERMOSTATIC VALVE CONTROL.



B. PRIMARY CONDENSER CIRCULATING WATER CONTINUOUSLY.



C. "KNOCK-OUT" BOX IN WHICH A CONSTANT LEVEL OF WATER AT CONSTANT TEMPERATURE IS MAINTAINED.

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There are several methods of offsetting this difficulty in some degree. One method is to condense the gasoline under pressure, say about 10 pounds, and increase the still temperature to about 245° F. Another means suggested is adding naphtha to the absorption oil after the oil has been treated in the scrubber. Adding about 2 per cent naphtha will materially decrease the volatilization losses, and if the naphtha is high grade will give a satisfactory end point. For example, assume that the still vapors contain equal volumes of butane (boiling point +33° F.) and hexane (boiling point 156° F.) and that condensation is taking place at 60° F. and atmospheric pressure.

Under these conditions hexane has a vapor pressure of 2 pounds per square inch, 1 cubic foot of gaseous hexane being equivalent to 156 cubic centimeters of the liquid. The vapor pressure of butane at 60° F. is 30 pounds per square inch; hence the butane will not condense under the assumed conditions. At the look box the hexane will be carried away by the butane in a mixture which contains two-fifteenths by volume of gaseous hexane, or 21 cubic centimeters of hexane will evaporate and be carried away in each cubic foot of tail gas. Now, if a quantity of naphtha equal to that of the hexane (156 cubic centimeters) is added before the mixture enters the still the partial vapor pressure of the hexane will be reduced to 1 pound, and only 10.5 cubic centimeters of hexane will evaporate, with a net saving of 50 per cent. The deductions are made on the assumption that no butane is dissolved in the hexane and that both gases follow the theoretical conditions based on the law of partial pressures of gases. From these data it is obvious that the addition of naphtha will give beneficial results.

In all instances the maximum saturation of absorbing oil compatible with efficiency should be attained, as with the higher saturation the distillation losses will be less.

"KNOCK-OUT BOXES" OR PRIMARY CONDENSERS.

Most absorption plants using mineral seal oil are equipped with "knock-out boxes" or primary condensers for removing the heavier hydrocarbons—carried up with the gasoline vapors—or "tops," from the mineral seal oil being stripped. These "mineral seal" tops cause the end point of the distilled gasoline to rise, and as absorption gasoline in the market usually demands a premium which is primarily contingent upon the end point of the product, these heavier vapors must be eliminated by some type of cooling apparatus such as the primary condenser or knock-out box. Plate VI, *A* shows a knock-out box in which the temperature is maintained at 190° F. by

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water sprays governed with a thermostatic valve. Plate VI, *B* shows a box of practically the same construction, with the exception of the thermostatic valve. The primary condenser shown in Plate VI, *C* is partly filled with water maintained at a temperature of 182° F., through which the still vapor pass. The heavy end-products that collect in these devices are returned to the still.

FEASIBILITY OF INSTALLATION.

On account of the wide variation in conditions in different fields and different plants, the application of absorption to the treatment of the residual gas may not be feasible or profitable at some compression plants. If the installation of an auxiliary absorption unit is contemplated, thorough absorption tests of the residual gas should be made under the average prevailing conditions. In this preliminary examination any dilution of the casing-head gas by air or dry gas should be corrected before the final decision as to the feasibility of installing the absorption process is reached.

Naphtha is recommended as the absorption medium wherever its use is practicable. Most casing-head gasoline plants blend the compression condensate with naphtha at the plant before shipping. At such plants the naphtha, after passing through the absorber, may be blended still farther with the raw compression condensate if a higher gravity is desired. If the plant is situated near a retail market the naphtha that has been used in the absorbers can be sold to the local trade.

An operator who installed an absorption system for treating the residual gas upon the bureau's recommendation states:

> We were handling about 500,000 cubic feet of gas per day and were recovering on an average about 700 gallons of 69° B. gravity gasoline. We installed an absorber at a cost of $800, through which we are now running our residue gas. We are recovering a minimum of 50 gallons and as high as 250 gallons per day of high-grade gasoline from this absorber. In addition to this we are using from 500 to 800 gallons of 50°–52° naphtha as an absorber and are increasing the gravity to 59°–61°. The increased value added to this naphtha, together with the quantity of gasoline recovered, confirms our prediction that this plant, as well as practically all other compression plants in the Mid-Continent field, is not obtaining proper efficiency in the recovery of gasoline from the gas.

A fact that should not be overlooked in contemplating the installation of an absorption system in conjunction with a compression plant, is that such an arrangement will make the compression process far more flexible. If engine or compressor trouble is encountered, the plant can be run at reduced pressures with the absorption system recovering the gasoline that would ordinarily condense in the accumulators. The vapors from storage tanks can be treated in the absorbers, thus avoiding the necessity for introducing them into the

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compression system and the danger of their making the compression gasoline "wild," or too light to hold.

During the year 1917 an average of 79,527,523 [a] cubic feet of natural gas was treated daily by the compression process. If all the residual gas from the compression plants had been treated by absorption methods—assuming that the residual gas contains 0.4 gallon per 1,000 cubic feet—there would have been a daily saving of 31,811 gallons of gasoline, or an annual increase in production of 11,611,015 gallons.

TESTING OF NATURAL GAS FOR GASOLINE CONTENT.

NECESSITY OF TESTS.

All of the tests made on the plants described in this paper were by the method and apparatus described in the following pages. This method of testing natural gas for gasoline content has been found satisfactory in testing rich or lean gases from wells or the residual gas from compression or absorption plants.

The natural-gas gasoline industry has had a rapid growth since 1913, when the first absorption plant was erected for recovering gasoline from natural gas. Absorption is now being successfuly applied not only to "dry" gas, but also to "wet" or casing-head gas, to still vapors, and to residual gas from compression gasoline plants.

In 1917 there were in the United States 102 plants using the absorption process, which had an annual production of 49,017,549 gallons, valued at $9,592,026.[b] This process has been one of the most important developments in the history of the natural gas industry, for it has not only saved and utilized a product that was formerly wasted, but has helped producers to meet the ever-increasing demand for motor fuels.

Methods for determining the gasoline content of natural gas have been described in several Bureau of Mines papers.[c] Tests of small samples of gas by specific gravity determination, by change in volume of gas in contact with an absorption medium, or by increase in volume of absorption menstruum merely indicate the quantity of gasoline in the gas and often lead to ambiguous results. The only accurate method of determining the gasoline content of natural gas that contains less than 1 gallon of gasoline per 1,000 cubic feet

[a] Northrop, J. D., Natural-gas gasoline in 1917: Mineral Resources of U. S. for 1917, pt. 2, U. S. Geol. Survey, 1918, p. 6g.

[b] Northrop, J. D., Place cited.

[c] Burrell, G. A., Seibert, F. M., and Oberfell, G. G., The condensation of gasoline from natural gas, Bull. 88, 1915, pp. 30–48. Burrell, G. A., Biddison, P. M., and Oberfell, G. G., Extraction of gasoline from natural gas by absorption methods, Bull. 120, 1917, pp. 17–24. Dykema, W. P., Recovery of gasoline from natural gas by compression and refrigeration, Bull. 151, 1918, pp. 102–103. Burrell, G. A., and Jones, G. W., Methods of testing natural gas for gasoline content, Tech. Paper 87, 1916, pp. 5–14.

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is to bring a given quantity of the gas into contact with some absorption medium and to separate the absorbed gasoline from the oil by distillation. The method outlined in this paper is effected by using an absorption apparatus that differs somewhat in design from any previously described, although it embraces the same principle of operation—that of the Friedrick wash bottle. This absorber, designed by the senior writer, has the advantage of being a rigid unit, with a large capacity for oil and consequently a larger gas capacity. By using larger volumes more representative determinations can be made, and the opportunities for error are materially decreased.

Before a plant for recovering gasoline from natural gas is constructed the quantity and quality of the gas to be used should be thoroughly examined. Often one sees plants that because of the lack of adequate testing of the gas were erected only to be abandoned as complete failures after a short period of operation. At present there is no excuse for such conditions existing as a result of inadequate preliminary examination of the gas to be treated. Too much emphasis can not be placed upon the importance of testing the gas before the construction of a plant is planned.

DESCRIPTION OF ABSORPTION TESTER.

The apparatus shown in figure 9 comprises a piece of 6-inch casing with five separate compartments, which can be connected in series. Each compartment has a ¾-inch gas inlet and a 2-inch gas discharge pipe or chamber, which extends to a point near the bottom of the compartment. From an opening near the top of the compartment extends a ⅜-inch pipe coiled around a 3-inch core with seven turns, through which the gas being treated bubbles and in which most of the absorption takes place. A minor modification, optional in the design and not shown in the sketch, is the use of needle valves at each extremity of the apparatus in order that gas may not be introduced too rapidly, or may be throttled to any desired pressure so as not to carry oil over from one compartment to the next. Also, the use of a needle valve on the discharge end enables one to regulate more easily the rate of flow through the meter, especially in tests at low pressures—that is, when the gas flows through the absorber very slowly. It is advantageous to use gate valves instead of drain cocks for drawing off treated absorption oil from the oil chambers, as such valves facilitate rapid work and eliminate the possibility of volatilization losses that exists when oil is allowed to spray through a stopcock under pressure into the container for collecting treated oil. Also, time can be saved by using small bull-plugged nipples in place of standard plugs, as they can be more easily removed and more rigidly connected to prevent leaks.

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METHOD OF USING.

To make the test with this absorber, 2,700 c. c. of "mineral seal oil," or enough to bring the level of the oil about 2 inches above the top of the 6-inch casing and well above the coil inlet, is accurately measured and introduced into each compartment. The most important requisite for absorption media is high initial boiling point, in order that in the subsequent distillation a quantitative separation

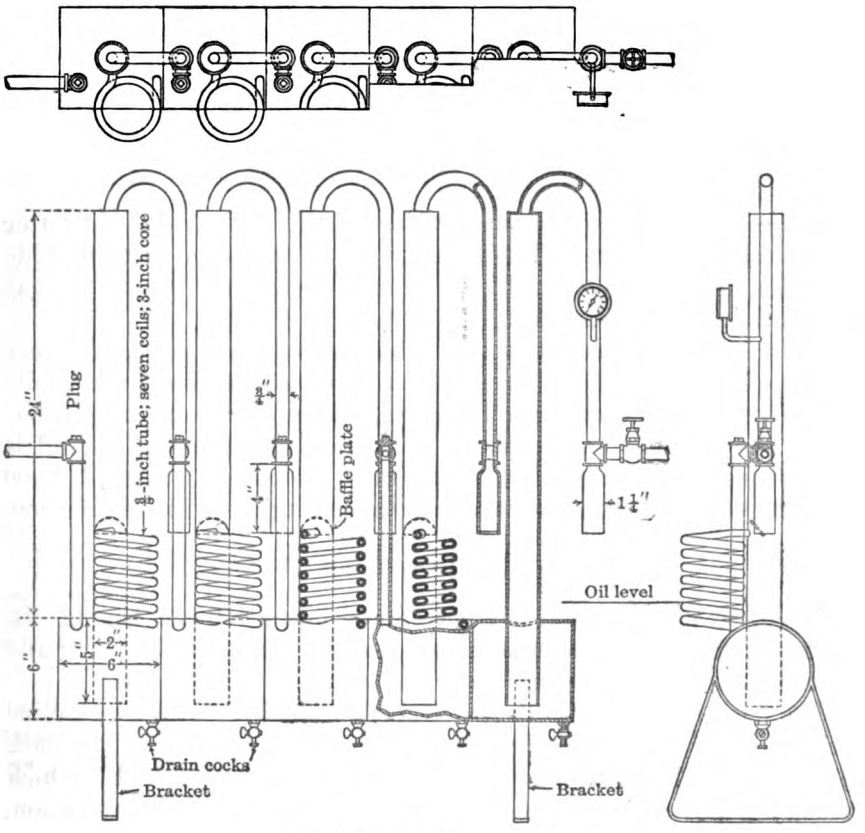

FIGURE 9.—Absorption tester.

can be effected. The oil used in the tests described in this paper had the following physical properties:

Properties of oil used in tests.

Gravity	36.0° B.
Initial boiling point	450° F.
Viscosity	51 Saybolt.
Flash point (Pensky-Martens closed tester)	271° F.
Fire test (Pensky-Martens open tester)	307° F.

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In most tests only the first three absorbers are used, but it may be expedient to fill the fourth compartment when examining rich gas flowing at low pressures or when running a large volume of dry gas in paralleling a 12-hour or day's operation of an absorption plant to determine the efficiency of recovery. The fifth compartment is not intended to be used as a container for oil, but to serve as a separator or oil trap in case any oil is carried over from the preceding compartment. A meter capable of accurately measuring 1 to 1,000 cubic feet of gas is connected to the discharge of the absorber.

The gas to be tested is allowed slowly to enter the apparatus with the discharge valve closed. When pressure equilibrium with the gas to be examined is obtained, or when the desired pressure is attained, the discharge valve is opened enough to permit the desired rate of flow through the meter.

The gas entering the absorber bubbles up through the oil, the latter absorbing the gasoline. The function of the pipe coil is to provide a long and intimate contact between the oil and the gas as the gas passes through the absorber.

After the desired quantity of gas has passed through the absorber the supply is shut off and the pressure is released, through the needle discharge valve, allowing all the gas to flow through the meter. After the pressure has decreased to atmospheric pressure the oil is withdrawn from each compartment and is accurately measured, 1,000 c. c. of treated oil from each compartment being kept for distillation.

DISTILLATION OF SATURATED OIL.

Of the treated oil 400 c. c. is introduced into a 500-c. c. Engler distilling flask connected to a condenser made of ½-inch brass tubing and surrounded with cold (ice) water contained in a metal box.[a]

The flask is heated by direct fire, slowly at first, and the gasoline driven out of the oil is collected in a graduated cylinder. The flask is heated until the vapor reaches a temperature of 350° F., which usually requires 20 minutes. If the oil has a very high saturation, it is allowed to cool 20 to 30° and again raised to 350°. This procedure is followed until practically no more gasoline is driven over and collected from the condenser.

The recovery of gasoline will depend upon the rate of flow, gasoline content of the gas, volume of gas treated, pressure, and the temperature of the absorbing oil. Optimum conditions as regards volumes of gas and rate of flow with gases at different pressures and gasoline content are given below.

[a] Am. Soc. Test. Mat. Year Book for 1915, vol. 15, pp. 568–569, and Year Book for 1916, vol. 16, pp. 518–521.

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Controlling factors in operation of test absorber.

Maximum rates of flow of gas (cubic feet per hour).	Pressure (pounds per square inch).	Maximum gas capacity.	
		Cubic feet of gas treated.	Gasoline, gallons per 1,000 cubic feet.
400	300	800	0.125
200	150	400	.250
100	75	200	.50
50	40	150	.75
20	Atmospheric.	100	1.00
		66	1.50
		50	2.00
		35	3.00
		25	4.00

The following data were obtained from a representative test of intake gas at a compression plant in the Mid-Continent field:

Results of test of intake gas at a compression plant.

Temperature of oil, 94° F.
Pressure of gas treated, 204 pounds per square inch.
Rate of flow, 133 cubic feet per hour.
Volume of gas treated, 302 cubic feet.

Item.	Compartments.		
	First.	Second.	Third.
Charge.....c. c..	2,600	2,600	2,600
Quantity recovered.....c. c..	2,700	2,600	2,630
Gravity of oil.....°B..	37.0	36.4	36.0
Quantity di tilled.....c. c..	400	400	400
Initial boiling point.....°F..	170	185	308
Gasoline in 400-c. c. sample.....c. c..	19.5	9.5	3.5
Gasoline recovered in each compartment.....c. c..	131.5	63.2	23
Proportion recovered in each compartment.....per cent..	60.5	29.0	10.5

Total quantity of gasoline recovered, 217.7 cubic centimeters (gravity, 78° B.).
Gasoline content of gas treated, 0.190 gallon per 1,000 cubic feet.

The gasoline content is calculated by using the following formula:

$$Q=\frac{1000}{G}\times\frac{C}{3785}$$

where Q is the gasoline content in gallons per 1,000 cubic feet of gas, G is the volume in cubic feet of gas treated, and C is the total number of cubic centimeters of gasoline obtained from the treated absorption medium.

Above certain limits the temperature of the absorbing oil has probably more effect on the efficiency of recovery than any other factor. In a series of tests of "dry" natural gas with all conditions constant, except the variable factor of temperature, a difference of 42 per cent in the volumetric recovery of gasoline for a gradient of

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30° F. was obtained, as is shown by the curve in figure 10. These changes took place between 90° F. and 120° F., and are undoubtedly due to the rapid increase in the partial vapor pressure of the gasoline fractions in the gas as the boiling points are reached. Probably no two gases will show the same results with the same variation in temperature, inasmuch as the characteristics of the gasoline hydrocarbons are distinctly dissimilar.

The data from which this curve was plotted were obtained from a series of tests using a constant quantity of oil (2,600 c. c. in each of the first three compartments), a pressure of 130 pounds per square inch, and a total volume of 200 cubic feet of gas which passed through

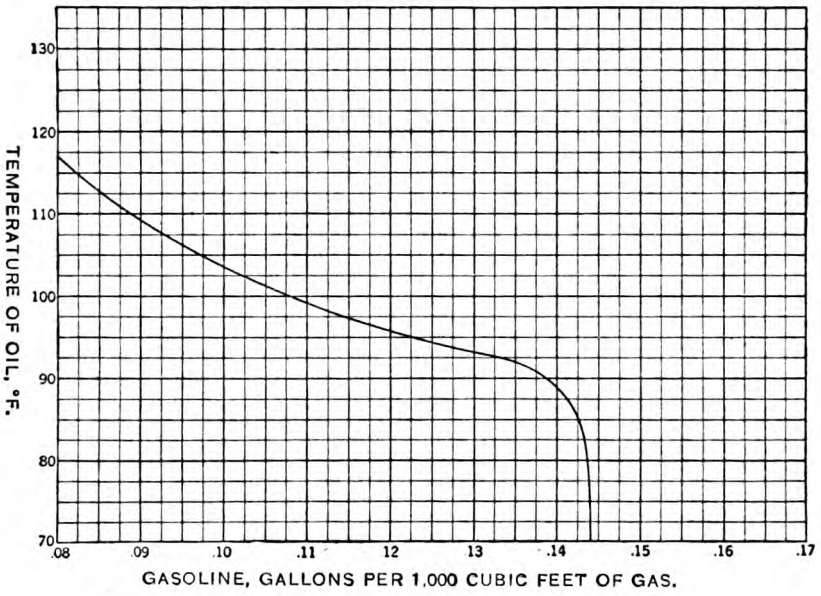

FIGURE 10.—Curve showing effect of temperature on absorption.

the apparatus at the rate of 2 cubic feet per minute. The point should be emphasized that the data obtained in this test can not be taken as a criterion by which to judge other natural gas. Samples of natural gas from different wells may have the same gasoline content, but on account of differences in the characteristics of the various hydrocarbons present may require radically different treatment.

The test absorber and the method described in this paper are recommended in preference to the use of the scrubbers mentioned in other publications, because they give more significant results when evaluating a gas with the idea of determining the feasibility of installing an absorption plant, or of ascertaining the efficiency of recovery at absorption or compression plants.

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Controlling factors in operation of test absorber.

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